To: R. Vogt
From: Fred Raab, 7 August 1989
Subject: Midlength interferometers

Evaluation of a three full length interferometer system versus a system with two full and one half length interferometers

In my opinion, if cost were not a driving factor, I would prefer a triple coincidence detector in which one of the interferometers was half the length of the other two. My reason is that I expect that such a system would give the most convincing signature to support a claimed detection of gravitational radiation. This reflects a personal prejudice in style of doing experiments. I would rather pay a price in sensitivity of an experiment to have more reliability in the result than to have a more sensitive system which gave less convincing data. However this is not a black and white evaluation and I think it is useful to elucidate where the reliability compromise is in a three full length interferometer system, and to determine what is the sensitivity price when one interferometer is half length.

R. Drever, Y. Gursel, and M. Tinto have just now produced an analysis which compares the relative burst sensitivities of triple coincidence detectors in which the third detector is chosen as either full or half length. While these results are new and have not yet had the advantage of scientific debate, the method used to obtain these results is the proper one to use. I cannot speak for the veracity of the actual numbers, so I will take them on faith. The worst case that I can think of is the situation when the half length system has half the signal to noise ratio for gaussian noise of either full length system and we are in the regime where the event rate scales as the third power of the burst sensitivity. The system with a half length interferometer would then have roughly half the burst event rate of a system with three full length interferometers.

With a system of three full length interferometers operating in the regime where event rate scales as the cube of sensitivity we could therefore expect to double the number of potential gravitational wave bursts detected. I presume that these sources will initially be quite rare. Thus with this system we may have real detected events much earlier than with a system which includes a half length interferometer. The problem is how do we convince ourselves and the rest of the world that these events are really due to gravitational waves and not some spurious cause.

The triple coincidence method allows one to rule out a chance triple coincidence based on the measured singles rates from the three interferometers using statistical methods. I think this can be done well irregardless of whether there is a half length interferometer in the detector. A question has been raised about whether correlated noise at site 1 would be a problem. I maintain that it is not necessarily a problem since one can tolerate a certain rate of correlated double coincidences at site 1, provided the singles rate for spurious events at site 2 is sufficiently low. These rates are amenable to measurement so one can tell for sure if there is a problem or not. In general we will need to work hard as we improve the signal to noise ratio for gaussian noise sources to ensure that the the singles rates due to non–gaussian events does not get too high. This will rely heavily on the use of auxiliary monitors to provide vetoes on pulses from individual interferometers. If we have a half length interferometer in the system, this vetoing process is simplified but we will still need auxiliary monitors. However we do not need to be as clever in the vetoing process. This is especially true in the case of locally correlated spurious events, a case which has not always been presented clearly in the past. I will give a separate discussion of this below.

The scenario which gets us into trouble without a half length interferometer in the system is when we get a triple coincidence which looks viable as a gravitational wave burst based on the statistical data from the three interferometers. How can we demonstrate that this is due to a real gravititational wave as opposed to some global external perturbation which is correlated over our two site baseline? The argument that we have a real burst will depend entirely on our ability to rule out all other causes using our auxiliary monitors. Position information may lend credibility to our case if for example we are consistent in time and space with a source detected by some other astronomical instrument. However it will be very hard to be convincing when claiming a discovery based solely on LIGO data. Auxiliary data will allow us to make negative statements about the possible false mechanisms which we have been able to think up prior to this event, but I expect that one will always be able to think up new loopholes. In the end the auxiliary monitoring system could get to be as complicated as our interferometers. With a half length interferometer in the system, we can use an extra piece of data on what a gravity wave must look like rather than a lot of data on how the rest of the world did not behave. This is the unique strength of including a half length interferometer in the system.

The recent analysis for setting thresholds on a triple coincidence detector gives a recipe for choosing these thresholds when one of the interferometers is half length. Curiously for a three interferometer system it works out to ensure that all triple coincidences provide sufficient resolution to use the length scaling information. This is not the case for our previous scheme which relied on quadruple coincidences. Even for events near threshold, length scaling will give useful information. While some spurious events can give almost any ratio of signal sizes in different length interferometers, the scaling window for a true burst gets rapidly smaller as the signal strength rises above threshold. This is another advantage of putting effort into detecting what a gravity wave is rather than what it is not.

Some notes on locally correlated events:

Statistically the noise output from a single interferometer has two components: a gaussian background and a non–gaussian tail. For reasons of brevity I will refer to all non–gaussian events with the generic term of "spurions." The reader is cautioned that this definition of a spurion may be different from what others mean by this term.

Some spurions are due to internal mechanisms which are specific to an individual interferometer, such as the sudden release of strain in a suspension wire. More worrisome are spurions which give correlated outputs in more than one interferometer. The degree of correlation for these events can vary. When some parameter common to more than one interferometer glitches, the affected interferometers can be expected to glitch. We can further divide the correlated spurions into two classes: those which give a definite ratio of glitch sizes in the affected interferometers and those which give glitches which appear to have random ratios of pulse height. For instance the low frequency components of a seismic pulse should be pulse height correlated in nearby detectors. Even here, differences in ground composition may give nearly random pulse height ratios for the same seismic input applied to different places. At high frequencies seismic related pulse heights would be a rapidly varying function of frequency and position and would appear random.

A key point missing in previous analyses of correlated spurions is how one's ability to measure that there is a correlation affects the strategy, even if the cause of the correlation is mysterious. The important number to track is the singles rate of unvetoed spurions. I will give some numbers based on the assumption that all three interferometers in a detector have the same unvetoed singles rate, n. I will demand a false alarm rate from the triple coincidence of one per ten years, which is reasonable when the rate of real events is very low. The triple coincidence method is useful and necessary for a rather small range of n, namely:

$$1/hr \leq n \leq 200/hr$$

When the singles rate is above 200/hr the triple coincidence will be overwhelmed and we cannot meet the false alarm specification. When the singles rate is below 1/hr, a double coincidence between separated sites is sufficient. If the singles rates exceed this range we must improve the vetoing procedure. Note that this argument is the same whether or not there is a half length interferometer in the system. However a half length interferometer may make the procedure on improving vetoes simpler.

Now let us assume that a certain fraction of spurions at site 1 are correlated. There will then be a certain rate of double coincidences between the two site 1 interferometers which are due to correlated spurions. Call this correlated spurion rate n_{c1}. We can tolerate a correlated spurion rate as long as the site 2 interferometer does not glitch at the same time. Assuming that there is no correlation between the two sites, we must fulfill the requirement that:

$$1/hr^2 \geq n_{c1} \times n$$

Now n is trivially measured, and n_{c1} can be determined by doing a statistical analysis of coincidences at site 1, using a few days worth of data. If the above condition is satisfied for n_{c1}, then the correlated noise at site 1 is not a problem. If this condition is not met, then we know that we need to improve our vetoing procedure and that until this condition is satisfied any triple coincidences we see should be treated with suspicion.

These arguments remain the same if we have different thresholds on the three interferometers, but obviously we must recalculate the relevant rate criteria. The reader may object that this analysis appears to assume that all noise is spurion related. This is because the gaussian noise makes little difference in the argument. Of course if we are successful in improving vetoes to get the singles rates down to say, 1/hr, we will need to raise our detector thresholds to keep gaussian noise down to the same level. However the event rate from gaussian noise falls off steeply with threshold, so the difference in strain sensitivity between 200/hr and 1/hr is only 20-30%.