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Notes on the Concept of a Half–Length/Full–Length Interferometer System

(Extended version, 8/28/88)

The addition of mid stations and half–length interferometers to a full length two–site system gives important advantages in at least five aspects of the research:

(1) They provide an important diagnostic tool in debugging and developing the interferometers.

(2) In pulse searches they can improve greatly the sensitivity to pulses occurring at the low rates to be expected in the initial discovery phase, and much improve the immunity of the system to spurious signals of instrumental origin.

(3) When interesting pulse signals are observed, they can show that what is being detected is a strain in space which gives a displacement proportional to initial separation of test masses, an important distinguishing characteristic of gravitational radiation. The system can make gravity waves provide a clear signature, not mimicked by phenomena such as neutrino bursts, correlated cosmic ray showers, or other exotic events.

(4) In searches for periodic gravitational radiation, they can provide discrimination against periodic disturbances such as those from the 60 Hz supply, from rotating machinery, and from resonances in the system itself.

(5) In searches for a stochastic background of gravitational radiation at kilohertz frequencies local half–length/full–length cross–correlation at each site may set more sensitive upper limits than obtainable in other ways. (However POSITIVE detection of stochastic radiation will still depend essentially on correlations between separated sites, even though the phase differences occurring when sites are separated by many gravity–wave wavelengths may make the latter a less sensitive experiment.)

More detailed comments follow.

When the idea of using mid–stations and half–length/full–length interferometers was conceived, the aim uppermost in my mind was to find a way to strengthen the experimental criteria that could give evidence that signals observed were in fact due to gravitational radiation. Without this, a two–site experiment can only say that something was observed that travels near the speed of light. Observations at three or four sites could improve the determination of velocity, and if enough sites observed the signal to give redundancy in polarization data this would give further evidence. However the total evidence might still appear rather meagre, and the simple evidence of linearity of displacement with baseline provided by midstations at the LIGO sites alone might be more convincing than analyses of miscellaneous observations around the world, and be much more easily obtainable.

This aspect of use of midstations is likely to be even more important now in view of the continuing controversies about claimed gravity-wave detections. However, the improvement in effective pulse sensitivity alluded to in item (2) may be initially more significant. A numerical example may make this clearer.

Estimates of Minimum Detectable Rates of Gravity-Wave Pulses in 2-Site LIGO Observations, with and without midstations.

The distribution of pulse heights observed from a gravity-wave detector almost always shows a "tail" of relatively infrequent large-amplitude pulses well outside the distribution expected from known sources such as thermal noise, electronic noise or photon shot noise, and not related to seismic disturbances. The origin of these spurious pulses is not certain: in the case of bar detectors it has been suggested that sudden releases of strain in the metal bars may be one cause. In laser interferometers similar effects would be expected – and Braginsky has suggested that the test mass suspension wires in interferometers are particularly likely sources of spurious pulses. The significance of these pulses is of course greatly reduced by coincidence operation of more than one detector; and the chance coincidence rate of spurious pulses is then likely to determine the minimum rate of gravity wave pulses detectable by the system as a whole.

It is difficult to predict the rate of spurious pulses to be expected from the LIGO interferometers. The test runs made with the 40-m prototype at Caltech after the 1987 supernova and a separate test with the 1.5-m prototype at MIT may give some indication. With the 40-m prototype Sheri Smith found, after applying all available veto information, a rate of 35 residual events per hour.[1] With the 1.5-m MIT prototype Dan Dewey found a rate of 22 residual events per hour.[2] These rates are higher than usually reported with bar detectors, but not unreasonably so. Cryogenic bars have been reported to give rates from 17 per hour to 10 per day, and the two wideband room temperature bars built in Glasgow in 1972 also gave spurious single rates in this range. The Glasgow experiments gave the additional information that the spurious pulses observed from two bars located together in the same building were almost totally uncorrelated – only one coincidence event was found in more than a year of operation.[3] It seems prudent to plan for spurious rates in the LIGO similar to those observed so far – and in this situation a requirement for 4-fold coinci-

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[1] S. Smith, Ph.D. Thesis, Caltech 1988, pages 95,96.

[2] D. Dewey, Ph.D. Thesis, MIT 1986, page 106.

[3] Nature <u>246</u>, 340 (1973).

dences, with half-length interferometers at each site as well as the full-length ones, can make a very large improvement in the minimum rate of gravity-wave pulses detectable, even in the presence of a high rate of spurious pulses.

Let us take some examples.

(a) No half-length interferometers.

In a simple 2-fold coincidence experiment the random coincidence rate is

$N = 2tn^2$, where n is the singles rate at each interferometer, and t is the coincidence resolving time.

For Maine-California coincidences t = light travel time, = 14 milliseconds.

Assume a singles rate $n = 20$ pulses per hour.

Then chance coincidence rate = 27 pulses per year.

I would regard this as a very serious restriction on detectable gravity-wave rate for initial experiments.

The situation can be improved for pulses giving a large signal-to-noise ratio by demanding that the pulses have equal amplitude at the two detectors. If we assume that we can discriminate say k amplitude channels of equal probability then this can improve the resultant chance rate by a factor of $1/k$. For $k = 5$, for example, the chance rate would be 6 per year.

I would regard this also as a rather poor rate sensitivity.

We could much enhance our chances of discovering gravity waves if we could make the background chance rate so low that observation of just one event in the first year of operation could be regarded as having a high probability of not being a chance coincidence. For this to be possible, the accidental coincidence rate would have to be less than about 0.1 coincidences per year. This may be very hard to achieve with just two interferometers. It is much more easily obtained if we use both half-length and full-length interferometers, so that 4-fold coincidence experiments become practicable.

(b) Half-Length and Full-Length interferometers.

If we look for 4-fold coincidences, with a resolving time t_1 between the half-length and full-length interferometers at each site, and a resolving time t_2 between the two sites, then the chance coincidence rate is given by

$N = 8t_1^2 t_2 n^4$, where all interferometers are taken to have the same single spurious rate n. Assume $n = 20$ pulses per hour, as before.

$t_1 = 0.5$ milliseconds

$t_2 = 14$ milliseconds,

Then the chance coincidence rate becomes $N = 1.1 \times 10^{-9}$ pulses per year.

This chance rate is completely negligible, and does not even require making any amplitude matching. Thus the use of the half-length interferometers may make even a single 4-fold coincidence pulse observed at the two sites highly significant.

It is worth noting that a 4-fold coincidence system of this kind is in fact very tolerant to a large rate of spurious pulses in the individual interferometers. Indeed a single rate of spurious pulses as high as 30 per minute would only lead to a 4-fold coincidence rate of 0.1 per year, which would not be very damaging. This near-immunity to uncorrelated spurious pulses may be an important risk-reducing feature of use of the half-length interferometers.

It should be remarked that the statistical examples just given assume that the gravity wave pulses are sufficiently above threshold amplitudes that they are detected by the half-length interferometers as well as by the full-length ones. The half-length systems will not give such a large advantage for marginal signals (although they will still improve sensitivity slightly). Nevertheless, the fact that most gravity-wave detectors seem to give significant numbers of relatively large "spurious" pulses makes it desirable to have an effective way of dealing with them, and this may be well provided for by the mid-station interferometers.

R. Drever, 8/28/88