Initial Notes on Strategy and Tactics in Operation of the LIGO over Two Stages in the Program: –

(1) Discovery of Gravity Waves;

(2) Study and Use of Gravity Waves.

(by R.W.P. Drever as of 12/15/88)

Summary and clarification of some important points:

(1) The concept of Phase A and Phase B.

For Phase A we will build and operate a system designed with two main aims:–

(a) to give the essential experience in the operation of detectors in a new sensitivity region required to enable the development of the highest–performance detectors practicable with available technology; and

(b) to give a significant probability (but quite likely less than 50%) for detection of gravity waves.

In Phase B the facilities will be upgraded so that with the experience gained in Phase A detectors of significantly higher sensitivity can be made operational, and much deeper searches can be made. If gravity waves of some particular type have been discovered during Phase A, then more detailed investigation of these waves, their sources, and the astrophysical phenomena they reveal, will be made. Concurrently, searches for other types of waves with more sensitive, and possibly specialized, techniques will be pushed deeper. If no gravity waves have been detected during phase A, then more sensitive searches will be made, probably using detectors specialized for particular types of signals as a way of enhancing sensitivity further. This will require a greater number of working detectors, and longer observation times, than in Phase A.

The step from Phase A to Phase B will certainly be helped greatly by any prior detection of gravity waves, but this should not be a defined pre–requisite, for if it were it could doom the project to never having a really high chance of success in wave detection. It is important that the switch to Phase B not be made dependent on detection of gravity waves but more on achievement of good search performance and the development of skills required for further advances.

It should also be made clear that the transition from Phase A to Phase B does not necessarily coincide with the introduction of outside users. The feasibility and benefits of having outside users will naturally increase as the work expands, and would certainly be more apparent as the number of detectors operating concurrently increases during Phase B – but the switch from Phase A to Phase B is not directly related to the number of collaborating researchers or scientific groups involved.

The real objectives in developing the observatory in two phases are:

(a) to spread the cost over a longer period, and

(b) to enable advantage to be taken in the second phase of experience gained in the first phase, so that a better ultimate performance and greater scientific output may be achieved.

(2) The Three Detector Classes

The three classes of detectors envisaged initially are likely to be:

(a) Developmental detectors – primarily for testing, verifying, and developing new detector concepts, and for making preliminary searches;

(b) Continuous search and monitoring detectors – designed and used primarily for the continuous search for transient events, such as supernovae, neutron star coalescence, and collapse processes in general. These detectors would also be capable of searches for continuous and stochastic signals at some moderate level of sensitivity – and would cover a wide range of signals in general. These are likely to be the first type of detector to go into full operation in the LIGO, as they would give the quickest general scan of the whole new field.

(c) Specialized, higher–performance detectors. These detector will be designed to cover some particular frequency region, or some particular type of signal, at higher sensitivity than practicable with the more general–purpose Continuous–Search detectors. Examples might be detectors specially designed for operation at low frequency, detectors using resonant recycling to search for narrow–band signals from pulsars, detectors using special techniques to enhance sensitivity for stochastic background searches, or for sweeping signals of particular kinds. These specialized detectors are likely to follow the other two classes, but their implementation does not necessarily coincide with the switch from Phase A to Phase B. There may well be advantages in operating such detectors during Phase A – perhaps for limited periods. And the development and operation of this class of detectors is not related to the introduction of outside users – these detectors are just as likely to be developed and used by the initial research groups as by any others. A much more important distinguishing aspect of these detector may be their need for some special requirement in the facilities – such as the use of larger test masses, of longer suspension wires, of special seismic isolation, or of special data handling or analysis systems. These detectors will almost certainly be the ones to achieve the highest sensitivity – and if the gravity waves are weak these are likely to be the ones to discover them.

(3) The Time Scale of developments in Phase A.

It will be very important to plan the work so that the chance of early detection of gravity waves is maximized, and also so that we have a detector operating from the earliest possible date in case a close supernova or other unexpectedly detectable event occurs early in the program. Even a single interferometer of far from maximum LIGO sensitivity could be extremely useful for this. A large gravity–wave burst associated with some unusual astrophysical event might be recorded in detail by such a detector, while showing up at poorer signal–to–noise ration in cryogenic bars operating at the time. The LIGO signal would certainly be the key one in such an event, and although such a happening would not be very likely, its importance for the development of the LIGO (and the field in general) could be very significant. To cover this, it would be important to get a first interferometer operating for at least part of the time very early, and it may be practicable to attempt this within 6 months of first getting access to the facilities. This first trial instrument would probably be unreliable and require almost continuous attention, but it will have been built concurrently with a near–twin instrument, which may be modified rapidly to overcome the problems encountered. The near–twin instrument would be put into operation as soon as it seemed likely to have reasonably reliable operation – and this would then become the first continuous detector. This could probably begin running well within a year from access to the vacuum facilities at the first site.

It may clarify the description if we introduce at this point the concept of interferometer "models", and also define some of the terms used here.

Definitions of terms used: –

(1) An INTERFEROMETER consists of four test masses, their seismic isolation systems, and the laser and optical system for monitoring changes in their relative separations.

(2) A pulse DETECTOR is made up of two interferometers at one site, one with full length arms and the other with half length arms.

(3) A pulse DETECTOR SYSTEM is made up of two detectors, one at one site and one at another site distant from the first. A complete pulse DETECTOR SYSTEM includes four interferometers (two half–length and two full–length).

The Concept of Interferometer "Models".

The development and use of the LIGO facilities will involve construction of a considerable number of interferometers. To enable this to be done economically and with minimum use of the limited manpower resources likely to be available we propose that the interferometers be designed to be of modular construction, using as many common components as practicable, and the components and the complete interferometers be manufactured in batches. There will be several varieties of interferometer design both in Phase A and in Phase B of the LIGO program. We may call the basic varieties of interferometer "Model A", "Model B", "Model C", "Model D", etc. We would propose to start production of LIGO interferometers with a first batch of nearly identical Model A interferometers, totalling initially at least 7 interferometers, all of the same design but with some differences in radii of curvature of cavity mirrors to allow operation with the differing arm lengths involved in the 40–meter and 5–meter prototypes, and in the 2 km half–length and the 4 km full–length LIGO facilities.

Tentative plans for use of the first 7 samples of Model A Interferometers might be as follows:

Interferometers AP1 and AP2 – for testing in the 40–m and 5–m prototypes;

Interferometers AF1 and AF2 – for operation over full-length LIGO arms, one for each LIGO site;

Interferometers AH1 and AH2 – for operation over half–length LIGO arms, one for each LIGO site;

Interferometer AH0 – the initial test LIGO interferometer, intended to reveal initial problems and to be replaced after a relatively short period.

This first batch of Model A interferometers would involve a minimum of 28 test masses for the main cavities alone, so small–scale quantity production could give significant economies in both cost and manpower.

The second basic design of interferometer in the Phase A of the LIGO would almost certainly be designed to cover a different range of gravity–wave frequencies or a different type of gravity–wave signal from that of the Model A Interferometer. We might call this the Model B Interferometer (although it is still for the first phase of the project). Again we would plan for an initial batch of about 7 Model B interferometers, to be used in a rather similar way to that indicated above for the Model A Interferometer, and occupying the second set of locations available in the vacuum facilities during Phase A of the project.

With these two detector systems, made from Model A and Model B interferometers, the Phase A stage of the facilities would be fully populated.

As Phase B of the LIGO facilities come into operation, we would plan to introduce further interferometer models. For example Model C might be a specialized interferometer for detecting signals from pulsars, Model D might be an enhanced replacement for the original Model A, etc. We would envisage a steady production of new interferometer models and replacement of earlier ones throughout the lifetime of the facilities, as techniques and new scientific requirements develop.

An important part of the concept outlined here is that the interferometers are designed from the outset for small–quantity production, rather than being built as individual scientific instruments. This is almost essential to achieve with limited scientific manpower the production and assembly of enough interferometers to give the maximum chance of detection of gravity waves at an early stage. This approach can almost certainly give us our best chance – if we were just to plan to build interferometers one at a time, it is very likely that detection of gravity waves would take so long that we could be in serious danger of running out of funds before achieving it. An appropriate combination of speed with economy in design, construction, and assembly of interferometers will be very important for the success of the project.

(4) Illustrative Schedule for Introduction of Interferometer Models during Phase A, and Scientific Results Achievable.

During Phase A of the LIGO each site would have facilities for housing up to four interferometers. For convenience we may divide the vacuum space available at any time at each site into two conceptual categories, which we might regard as forming a "Test Station" and a "Run Station". At each site the Test Station and the Run Station are each capable of accommodating two interferometers – which will frequently be full length and half length versions of the same Model, although this will not always be the case. In general the Run Station will be occupied by interferometers which are in continuous undisturbed operation; and the Test Station may accommodate interferometers which are being tested or developed as well as ones which are in full, but not necessarily undisturbed, operation.

(Alternative names could be "Development Station" and "Operational Station" – although in practice operational runs would take place in both stations. For clarity, and brevity, here we will use the words "Test" and "Run").

The way in which the Test and Run Stations are implemented will depend on the precise configuration of the vacuum tanks, and can change with time. As an example we may take the case of a central building containing a corner tank, two mass tanks, and a splitter tank. Then a Test Station could comprise the corner tank along with either a half–length tank or a full–length tank in each arm. A Run Station could comprise a mass tank in each arm, a full–length or half–length tank in each arm, and the splitter tank. Other ways of implementating the Test and Run Stations are possible, but this does not affect our functional description and scheduling strategy.

We now outline a possible schedule for deployment and use of Model A and Model B interferometers in the two sites during Phase A of the LIGO, along with potential scientific results achievable at each stage. To simplify the description we will make the assumption that entry to the vacuum facilities at the first site occurs at a definite date, and entry to the vacuum facilities at the second site occurs one year later.

Possible Schedule for Introduction and Use of Each Interferometer.

(Shown for clarity by location of interferometers of each Model number)

In this table all dates are measured in months from the date of initial entry to the vacuum facilities at the first site. Estimated dates are very uncertain, and almost certain to change.

40-m Proto	5-m Proto	Site 1 Test	Site 1 Run	Site 2 Test	Site 2 Run	Date mon.	Science Possible by end of period
AP1	AP2	))				-12 … 0	(Instrument development)
"	"	AHO				0 … +6	Low-sensitivity intermittent coincidence rare-event monitoring with cryogenic bars
"	"	AHO	AF1			+6 … +12	Non-continuous one-site coinc. monitoring plus low-sens. coinc. check with cryo bars
"	"	AHO	AF1	AH1		+12 … +18	Non-continuous 2-site 3-fold coinc. +bars *Start of medium-sensitivity searches
BP1	"	AH2	AF1	AH1		+18 … +20	As above, but fewer interruptions
"	BP2	AH2	AF1	AH1	AF2	+20 … +24	2-site continuous 2-fold coinc. plus non-continuous 4-fold coinc. (Bar-independent)
"	"		AF1 AH2	AH1	AF2	+24 … +26	As above (this step is clearing space in Test Stn.)
"	"	BH1	AF1 AH2	AH1	AF2	+26 … +32	Full 2-site 4-fold continuous searches Start of B monitoring. Low-sens. B/A coinc
"	"	BH1	AF1 AH2		AF2 AH1	+32 … +34	As above (Clearing Test Station of Site 2)
"	"	BH1	AF1 AH2	BH2	AF2 AH1	+34 … +40	Full 4-fold continuous A searches + non-continuous 2-site 2-fold B searches
"	"	BH1 BF1	AF1 AH2	BH2	AF2 AH1	+40 … +44	Full A searches + non-continuous 2-site 3-fold B searches
"	"	BH1 BF1	AF1 AH2	BH2 BF2	AF2 AH1	+44 … +48	Full A and B searches. (Capacity of Phase A facilities saturated. Phase B started?)

Notes:–

(1) It should be noted that we have assumed here that scientific manpower is so limited that installing and debugging any interferometer can only be done at one site at a time, and even after the experience of installing 11 other interferometers it still takes 4 months to put one in. This is probably unduly conservative, and significantly faster progress may be possible, particularly in the later stages.

(2) In practice it would be intended that Phase B would start before the time indicated here for Phase A, and at that point the program would change significantly – and the schedule indicated would become inappropriate. The schedule indicated is thus conservative in this respect also and assumes an undesirably long delay in the switch to Phase B.

(12/15/88. R. Drever)

(This report includes two earlier notes, dated December 4, 1988 and December 11, 1988.)

Appendix. Notes from an earlier Report.

I think that for the first few years of operation of the system, when a major effort is going into making an early detection of gravity waves and there is a lot of experience to be gained, work requiring access to at least one of the test masses might take place at a rate varying from a few times per week to several times per month. Interruptions of operation of all of the interferometers at these rates would be very undesirable. The rate of interruptions may fall of after several years – but I would expect it to remain significant indefinitely since new experiments and techniques would be continue to be introduced and developed.

In this connection it may be useful to indicate a possible scenario for work with the interferometers near the start of operation of the facilities.

Possible Scenario near Start of Operation.

The prime aim of the early work will almost certainly be achieving the detection of gravity waves or the setting of useful upper limits as early as possible, and the whole strategy of the early phase is envisaged as designed to do this. A possible program could be as follows:

The first interferometer is put into the facilities as soon as they become accessible, and is then debugged and made operational as rapidly as possible. Although the system will have been pretested in a prototype facility, it can only be expected that some new problems will be encountered on first putting light through this 100–times–longer system. A major effort will go into overcoming or avoiding these problems rapidly; and the interferometer will be run at all practicable times at this stage, with data being collected and analyzed as far as possible even though it may be imperfect and limited. As soon as this first temporary interferometer is working well enough to allow some effort to be switched into upgrading a second copy according to the experience gained, then the second would be installed in another tank and work would go into getting this to run reliably and well. At this stage frequent access to the second interferometer would likely be necessary – perhaps daily at first, then perhaps a few times per week, with perhaps work lasting a day or two at a time on some of the openings. Eventually access times might stretch out to a few per month, but for all this period the possibility of working on one of the instruments while running of the other one continues without disturbance could be very important indeed.

As soon as the second interferometer is working reliably enough for steady use it in turn would go into continuous operation, and then effort would be switched to renovating and upgrading the initial one, or beginning the debugging of a third.

A process similar to this might well continue for several years at least, with a new interferometer being debugged or an old one renovated while existing ones continue to collect data. I would expect opening of one or other of the tanks to occur at least once per week – and possibly more often – for several years, until the technology gets mature. And possibly fairly frequent openings would continue even then.

I would expect a process somewhat similar to that outlined to take place at both the first site to go into operation and at the second, and indeed to be fairly general. I think it is an effective way to maximize chances for earliest possible discovery of signals, while covering as far as practicable the possibility of occurrence of an unexpected supernova or other event very soon after startup of the system – an event which could make the project look bad if all interferometers at one site were out of action at the time.

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