LIGO-T880044

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Operations Scenario
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Warning:

This is an early draft laid out for content and inviting comments and is not meant to be complete.

I. The Basic Scenario:

The operational scenario for the LIGO facilities naturally splits into two phases (Phase A and Phase B) which then subdivide into subscenarios (parts which occur in the fulfillment of a particular phase of operations) and branching scenarios (which occur only if some hypothesized events take place). In Phase A we start with the completion of the site buildings and the the beam tubes, and have installed at the two sites the minimum set of hardware necessary to prove that we can get long baseline interferometers working and to make the first detection of gravity waves. In Phase B we add the rest of the hardware to convert the LIGO into a full blown astronomical facility which can support both in-house astronomical and R/D work, and the experiments of an outside user community. The rationale for this phased approach is to move quickly after construction is completed toward detecting gravitational radiation with the least amount of distraction from these efforts. Once the ability to detect gravity waves is an established fact, we will be in a far better position to implement effectively the upgrades that will result in the best possible astronomical facility, and we can then also better afford the time sink that will be required for this second mission of the project. During both phases, we will be operating both the interferometers at the LIGO sites as well as the campus prototype interferometers. The campus prototypes will serve a crucial role in interferometer R/D, hopefully performing all technology development not requiring the long baselines which are only available at the LIGO sites.

The Basic Support Structure:

Each LIGO site will ultimately house three detectors: a dedicated search detector, an R/D detector, and an outside user detector. Only the search and R/D detectors will operate during phase A. Each detector will consist of one full length and one half length interferometer. The rationale for two interferometers per detector is documented elsewhere (see Ron Drever's memo on full length/half length requirement). There will in addition to the main interferometers be anti-seismic suspension point interferometer(s). The rationale for the anti-seismic interferometer(s) is to act as a diagnostic for seismic related mass motion and to provide active vibration isolation at the suspension point. The anti-seismic interferometers will not require additional vacuum chambers but may require extra vacuum pipes.

Each LIGO site will have five buildings which house the interferometer stations and daily activities. The main experimental hall and office/shop structure will be in the corner building and its annex. In addition there will be two end station and two mid station buildings which house only vacuum equipment and some electronics. The buildings will be joined by 2 km lengths of vacuum tube in an appropriate enclosure.

Each LIGO site will have an on-site computer system for instrumentation monitoring, control functions, and data collection and storage. The R/D detector will probably require data analysis support from the on site computer. This will enable a modification to made during the work shift, a performance run to be accomplished during the off shifts, with data analyzed (or at least in decent shape) for the next work shift to make further adjustments and work decisions. On the other hand, data from the search detector will probably be accessed for analysis off-site. In principle it should be possible for scientific personnel to use the search detector without ever travelling to the remote site.

The corner building annex will contain electrical and mechanical shops to support operations, as well as shipping, handling and storage facilities. The mechanical shop will be used principally for assembly of components shipped to the site which are being prepared for installation into the system and for minor repairs or modifications to on-site hardware. It should not be viewed as a fabrication facility. It probably will contain hand tools, measuring tools and jigs, a drill press, and hand operated sheet metal forming and punching tools. Fabrication will be contracted to outside shops. Quick alterations (jobs which take several days) will be handled by outside shops with shipping done via Federal Express or equivalent. There will occasionally be needs for alterations requiring only a few hours of labor. For this purpose we should plan to use some local shop within 1/2 to 1 hour drive of the site, which will agree to work for us on a drop-in emergency basis. If this is not feasible we may want to consider having a small lathe and mill on site. (Personally, I would rather avoid such heavy machinery.)

The function of the electrical shop will be to support equipment tests and minor alteration/repair jobs (minor means the two day Fed Ex round trip time would be comparable to labor time). It functions in a spirit similar to the mechanical shop.

The shipping/handling facility will be a key component of the remote sites. It will handle traffic between the site and either the campus prototypes or industry. It will provide the obvious shipping/receiving function, inspection/verification, and serve as an interface between the dirty outside and the clean experimental hall environments. Shipping/handling requirements are in a separate chapter below.

There will be office, meeting, and reception areas to serve the needs of visitors and those on work furloughs at the remote sites.

II. Phase A Operations:

The phase A facility will have the completed builings and long baseline tubes and will contain the minimum number of vacuum chambers to support two detectors at each site, each detector consisting of a full length plus half length interferometer. Once both detectors are operational we will commit to running one of the detectors in a dedicated search mode (the search detector) and one in an R/D mode (the R/D detector). This will resolve the issue of when to improve detectors and when to take data. Search data will accumulate on a full time basis (as full-time as possible) while providing an experimental test bed for developing better detectors. So as not to compromise the full time capacity of the search detector we will require a very flexible vacuum system which allows interruption of one detector with only a minimal down time for the second. This requires that the second detector remain under high vacuum, and that power to the second detector is move it?

interrupted for the minimum amount of time. Periodically the R/D detector will achieve the capability of long term operation at much better sensitivity than the search detector. When this occurs we will need to commit the R/D detector to search mode, retire the old search detector, and commit its vacuum tanks to accept the newer R/D detector. Our commitment to maximize the on-time of a search detector requires that the vacuum layout allow that the search detector can be placed in any of the vacuum tanks. If this were not the case, then at the time of switchover we would need to shut down both detectors for the time required to move the R/D detector into the specialized tanks suitable for a search detector. Such switchovers could then result in the two site LIGO system not having any search mode capability for periods of several months each time such a switchover occurred. For a more detailed rationale concerning the need for vacuum system flexibility see Ron Drever's memo : "Notes on Reasons for Incorporating Gate Valves in Test Mass Tanks,..."

By its nature the search detector in steady state mode will run around the clock every day of the year except for emergency? service and for very short interruptions when access to the long tubes is blocked to lift components of the search detector? There will probably be some routine schedule of short downtimes for routine service (such as occasional mirror cleaning, or replacement of laser plasma tubes). Otherwise it will operate unattended and be monitored by computer to ensure that it operates properly. Data analysis supporting the search detector will be done off-site, except that some rudimentary on-line analysis may occur to tag interesting events or veto glitches in the data archiving process.

The R/D detector will be worked on frequently, perhaps on a daily basis. However R/D operations will probably have an adverse effect on the search detector's environment, and so will probably be restricted to one shift of manned operation per day. This will allow two shifts of cleaner data runs on the search detector. However powering down the R/D detector for two shifts per day would be harmful in many circumstances due to the anticipated long equilibration time between optical components and laser power load. Thus except for periods when the R/D detector is brought up to air for work, it will be fully powered (including instrumentation) around the clock. This suggests that manual work on the R/D detector be done during the one shift, but that the instrument be accumulating test data during the other two shifts. Development of the R/D detector may at times require frequent access to components internal to the vacuum. This should be minimized when this will cause interruptions of light to the search detector if possible. Where possible such beam interruptions should be coordinated with routine service of the search detector.

lift search

For some developmental work, the R/D detectors at the two different sites may be doing different things. However it is plausible that most of the time, progress on a new concept may require running the R/D tests in tandem between the two sites. My rational is that we will be a regime where the discrimination against spurious events will require the full power of coincidence measurements between remote sites. Even if spurious events were not the problem, system performance anomalies specific to one detector (say an aging component) can be isolated by the lack of a problem at the other site. To avoid committing unnecessary manpower to the remote site, we should expect that simulation tests supporting the R/D detector would be done at the campus prototypes.

Experienced scientific personnel would be retained as much as possile on the campuses.

This puts certain demands on the data link between campuses and the R/D detector. It would be required that all data on the R/D detector be accessible on campus to be used in decision-making for further work. Two lab-competent workers would serve as hands and legs at the remote site. Obviously the on-campus personnel will need to travel to the site on work furloughs to provide sufficiently tight coupling in the system. However these trips should be well planned so we do not sacrifice our best manpower unnecessarily.

The Evolution of Phase A:

Upon completion of construction the first task will be to install the first detector, and get it to operate successfully on the long baseline. To get both interferometers of the first detector installed at each site, shaken down, and to work out issues associated with making two sites work as a single unit (including debugging of the coincidence techniques, and implementation of data analysis algorithms) will probably take a minimum of two years. (Remember that construction at the second site is only completed one year after the first site opens in our current plan.) The first R/D detector will be installed @ 2 sites? during the third year and first shakedown as a complete unit (two interferometers) might ~~occur~~ be completed near the start of the fourth year. The reasonable time for the first switchover (replacement of a search detector with an R/D detector) will probably occur in the fifth year of operations. The success of such a time line will depend heavily on the success of campus prototype operations. With good luck this time line could be accelerated, surprises and difficulties could slow it down. After this initial period the facility would have achieved steady state and would operate in a switchover mode until detection is achieved.

Vacuum Layout:

A vacuum chamber layout for phase A has been proposed (see Figure 1.). The corner building will house a 14 foot diameter corner chamber, two 8 foot diameter airlock chambers, a 6 foot diameter splitter chamber, and connecting plumbing. The end station buildings will each contain a single airlock chamber, and a 12 foot diameter end chamber. The mid station buildings will each contain two airlock chambers. The corner and end chambers are of conventional vacuum design and are isolated from the system vacuum by horizontal 6 foot gate valves. Sections of 6 foot diameter dummy tubes serve as place-holders for the rest of the chambers that will be installed during phase B. The use of this phase A configuration might evolve as follows. The first interferometer will be installed in the conventional chambers (end and corner chambers). The second half length interferometer of the first detector will also use space in the~~se~~ corner chamber~~s~~ and will occupy one of the airlock chambers in ~~the~~ each mid station. Thus in the intial configuration we will have in the corner chamber the beam splitters and associated optics, and four test masses. Each end chamber will house one test mass and a test mass will be housed in one of the airlock chambers in each mid station building. This will allow us to get the first detector operational without the complexity of using a splitter chamber. If we build the full length as the first interferometer we avoid the use of the airlocks entirely in getting the first LIGO interferometer shaken down. The first R/D detector will be housed entirely in airlock chambers, two test masses per chamber in the corner building, and one per chamber in the end and mid station buildings. The first R/D detector will also make first use of the splitter chambers. Thus the complications of the more flexible components of the system are mostly delayed until a search detector is accumulating data.

Lasers:

The laser power for the first detector in LIGO will come from large frame ion lasers such as the INNOVA-100 or its successor. Hopefully the first drive for improvement in an R/D detector will be a large power upgrade by introducing the newly available Nd:YAG lasers. If the YAG technology is not yet ready at this stage, we could make significant progress by introducing vibration isolation systems which would allow us to increase sensitivity at lower frequencies, while running with ion lasers. Even with ion lasers, shot noise limited performance would allow us to get down to the standard quantum limit (SQL) near 10 Hz. Thus a program which emphasized work on vibration isolation, thermal noise, and other stochastic noise sources could get us very good returns and possibly even gravity waves without YAG technology. Obviously we would like to install higher power as soon as it was feasible. The electrical budget will allow four INNOVA-100 class lasers to run at full output, and could accomodate about two orders of magnitude more light power when the facility is YAG'ed.

Possible Alterations to Phase A:

To further define the scenario for phase A is difficult without an estimate of when gravitational radiation will be detected. However we should plan that phase A could continue until we reach far into the sensitivity limits anticipated for advanced detectors. Assuming that work at LIGO is successful in advancing the state of the art of detectors, and that detection eludes us because the sources fail to be strong enough to cooperate with our good efforts, then we may be required to add additional vacuum hardware or make other changes to the facility before phase B commences. For instance, unanticpated new tricks may be required which use up more space in the chambers, or bigger test masses may be required, etc. Nonetheless the spirit of phase A should prevail, namely we do not operate more than two detectors at each site until detection is achieved. However in this branch scenario we must anticipate that the earlier conceptual designs may become cumbersome. This could be corrected for example by adding airlock chambers so each test mass has its own chamber to relieve crowding. Or we may find that splitter and mass chambers will require modifications such as changing ports or adding plumbing because of new knowledge gained in years of successful operations. This may even entail scrapping of some chambers for a better design. The feasibility of doing this will be determined by our patrons, but if we have been successful in meeting all experimental criteria for the project this may come about. Another possible outcome in this scenario is that if we prove that we can achieve the levels of sensitivity that we propose but the sources are not there, a clamor may arise from the outside community that they be provided access to the facility to set up different types of search detectors. For instance while we have burst searches and R/D going, outside groups may demand that they be allowed to man a periodic source detector or some other experiment. Thus if we prove technological maturity but do not make detection, others could well force implementation of phase B without detection being achieved and thus not on our time line.

In the event that detection eludes us because we fail on the technological end, we will probably be shut down. This most strongly argues the rationale for concentrating our efforts on two detectors per site plus the campus prototypes.

III. Phase B Operations:

After successful detection of gravity waves, the facility will be upgraded by adding the full complement of vacuum chambers and lasers that we now anticipate. Presumably there will be some additional office and shop space required by the outside user community.

Most likely detector R/D will continue throughout phase B, but more manpower will be devoted to data taking and analysis. Similarly, the search detector will operate on a stand-alone basis as it did in phase A. The additional outside user detector will probably at different times serve the role of both searching and R/D. Also its activities may or may not be coordinated between the two sites. For instance we could envision that for periodic source searches (where Doppler shifting identifies a source as extra-terrestial) different outside users could be conducting independent experiments at different sites.

In addition to the support level required for the CalT$\overset{6}{\text{e}}$ch/MIT collaboration, the facilities will need to provide for extra support required by the outside users. Presumably the outside users will bring in their own technical support people. The LIGO shipping and handling facilities would be shared. However there will be an increased demand on shops and staff time associated with the new experiments. Most likely we will not be able to plan well for this until we see what the outside usage will look like.

The Transition from Phase A to Phase B:

The additional construction for phase B will require a shutdown of all operations at the remote sites for a period of at least $\overset{\text{2 mos.}}{\text{one}}$ year. Exactly when this occurs after detection will be a painful decision. During this period all of the scientific efforts will occur on the campuses. R/D work will continue at the campus prototypes, but analysis of the detected events and reanalysis of previous data will probably be receiving the foremost effort. It is highly plausible that with the knowledge of what events really look like, further events could be detected in the old data, during the time that all detectors are down. Once the facility resumes operation in phase B, searches and R/D efforts will probably be driven less toward increasing sensitivity and more toward looking in the right places.

Sometime after first detection, considerable effort will go into the physics of gravitational radiation, as opposed to its use as an astronomical tool. It is not obvious where this break will occur and how deep a break it will be. Discovering more sources would certainly help in understanding the physics, but with a better understanding of the physics one would probably find more sources. While we cannot now ponder how these decisions will be made, they will have a practical impact on when the transition from phase A to phase B will occur. We ought to think about a scenario for how many events we will want and what follow up experiments we will need before we are willing to shut down the remote sites for phase B construction.

IV. The Role of the Campus Prototypes:

I am assuming that throughout phase A and Phase B the level of effort at the campus prototypes will continue at the current level. While I agree with most of the points in the previously quoted memo by Ron in a general way, I believe that opening of the vacuum chambers at the remote sites will be painful and costly in manpower. To minimize this, we should adopt the rule that anything to be installed at the LIGO sites should be fully developed first in the campus prototypes. This means that the only reason for installing interferometer hardware in LIGO is that no more shakedown can occur without access to 4 km tubes. It also means that all hardware should have its reliability for hands off operation tested at the prototypes, so that adjustments at the remote site (i.e. most tuning up) can be done without opening the vacuum chambers. This will result in delaying initial trials in the full length system but ought to make them go faster once the system is installed. This requires a level of discipline that is nonexistant in current prototype operations. The remote facility need not be viewed as a space operation, where no adjustments can be made after launch. I would view it more as a balloon gondola which should fly unassisted but can be brought down for emergency work, but at great cost in manpower.

Science team members (excluding the facility manager and on-site technical personnel) would live near the campuses and would only travel to the site for short periods (typically a week or two and rarely more than six to eight weeks for some). The R/D detector will require a rotation of the science team members through the site in normal operations. This will be necessary to maintain tight coupling between on-site and campus operations. Most hands on work would be accomplished by technical staff and students. Of course there will be "all hands on deck" situations as when a new R/D detector is first installed. This mode of operations will be similar to that practiced by the accelerator community.

The bulk of scientific and engineering work will center on the campus prototypes. It is here that detector development will be made or broken, aided by performance data from the field. This will require a major commitment to capital spending on the prototypes. At the very least one of the campus prototypes must be hardware compatible with both remote facilities (minus the 4 km tubes). This is the only way to achieve certain prototype operations and make most effective use of manpower. For instance tests of mirrors or new cavity designs will require access to the same lasers as at the remote facilities. To try to design this capability for prototype work into the remote facilities would be clumsy, expensive in dollars, and would waste a great deal of manpower on travel between the campuses and the remote sites. Similarly, if test mass and optics layouts are to have any reasonable chance of working quickly when installed at the remote sites, then they will need to be assembled, instrumented and tested in the same configuration and envelope that they have at the remote facility. The remote facility space will too valuable to be wasted on unproven experiments or apparatus. Even before LIGO operations start, some pieces of hardware intended for LIGO (such as one of the airlock chambers) should be installed in one of the prototypes for complete checkout. Presumably one of the campus prototypes would switch over to YAG operation before this technology is introduced at either of the remote sites.

This rule could relaxed somewhat for cases of redundacy. For instance I anticipate that the first detector in LIGO would have four test mass assemblies in the corner chamber. Presumably the test masses could be designed in a modular fashion. The modules for one complete interferometer could be run as a complete interferometer at one of the prototypes. Once shakedown exceeds the capability of the short prototype, the modules are installed as the first LIGO interferometer. Four additional modules are fabricated and fully checked out at the prototype and then shipped to be installed as the second interferometer of the first detector. Thus the prototype would not need a clone of the end chamber, if the interfacing between modules is handled at the remote sites. This would of course require appropriate engineering of the modules to avoid any possibility that they will not merge smoothly on site.

To ensure the best chance of trouble free operation when new hardware is installed at the remote sites, the prototyping work will need to emphasize reliability and minimum hands-on nursing of components. This will require engineering expertise and a systems approach to design. After scientific feasibility of hardware is proven, the components will be modularized and certified by engineering personnel before release for use in the LIGO.

The proper integration between the campus prototypes and the remote sites will require a scenario for movement of hardware between campuses and remote sites. This will be treated in a separate chapter below.

V. Manpower:

There is a natural separation between manpower required at the remote sites and on the campuses. The on-site manpower will require certain support structure at the sites. These issues are treated below.

On-Site Personnel:

Campus Personnel:

Personnel Support Requirements:

VI. Shipping and Handling of Equipment:

VII. Operations Budget: