NATIONAL RADIO ASTRONOMY OBSERVATORY
Charlottesville, Virginia

~~January 4, 1989~~ Feb 6 1989

M E M O R A N D U M

To: Paul Vanden Bout

From: K. Kellermann

Subject: 300 ft replacement

1) Neil Cummins called last week to tell us that a letter from the Govenor as well as one from the Maine Congressional delegation has been sent to Bloch. I am not clear if this was one letter signed by all or separate leters. I thanked him for his interest (although I am not sure if any of this is helpful). Burke says that Byrd said that he would not interfere with Mitchell's plans. Burke also said that at the AMOG, Pat Bautz pointed out that the 300 ft was category C, etc.

2) As you may be aware we have had had telephone inquiries from Krupp/MAN and Daytron expressing their interest in making a presentation to NRAO. Peter has already met with Krupp/MAN in Germany, but we have not had any real discussions with Daytron, who Lee feels have design experience as good as TIW (ie better than RSI). Peter, Larry, and I all feel that we probably should not be spending more time, or wasting theirs until we get some signals that the project is going ahead.

However, it may be important, particularly in the case of Daytron to extend the equal treatment concept. At the RSI meeting today, Dick Thomas specifically asked me if Daytron had been here. I told him the truth, that they had not, but we have talked with them. Hein feels rather strongly that we should talk with them as they almost went to court with RSI and Hein feels that they would not hesitate to take us to court.

Congressional Research Service
The Library of Congress

Washington, D.C. 20540

# Memorandum

February 17, 1989

TO : The Honorable Robert C. Byrd and John D. Rockefeller, IV
Attention: Carol Mitchell and Amy Berger

FROM : Richard Rowberg and James Mielke
Science Policy Research Division

SUBJECT : **The Green Bank Observatory Proposals**

On November 15, 1988, the 300 foot diameter radio telescope at Green Bank, West Virginia, collapsed and was totally destroyed. The telescope was part of the National Radio Astronomy Observatory, headquartered at Charlottesville, Virginia, which is funded by the National Science Foundation. The loss is a severe blow to the United States astronomy effort, and calls for its replacement have come from many of the Nation's astronomers. The NSF, however, appears reluctant to commit to a replacement. Instead, it has offered to build the eastern segment of the proposed laser interferometer gravitational observatory (LIGO) at Green Bank. The LIGO, which is designed to detect gravitational waves from stellar objects, is a joint experiment which would be run by California Institute of Technology and Massachusetts Institute of Technology. The NSF has committed to the project, but the funding request for FY1990 is only for continued R&D on the detector at the same level as FY1989. Currently, the eastern segment of the LIGO is scheduled to be built near Columbia, Maine.

The principal issue is whether the LIGO is an adequate substitute for a new 300 foot telescope in terms of benefits to the state of West Virginia and to the Nation's scientific enterprise. This paper first presents an analysis of five specific issues that address the scientific controversy and the benefits to West Virginia. Following that is a section which discusses the scientific background to the issue. This analysis is not intended to be an argument about building the LIGO, but rather a discussion of the merits of building it at Green Bank instead of replacing the 300 foot radio telescope. Indeed since the LIGO is likely to be built in any case, the principal scientific question centers on the consequences to radio astronomy of not replacing the 300 foot telescope.

## ISSUES

There are a number of issues that address the question of the relative merits of building either of these instruments at Green Bank. Information to address these issues was obtained from conversations with scientists either participating in or familiar with radio astronomy and gravitational waves, and from the literature.

1. **Just before the collapse of the 300 foot telescope, the entire Green Bank facility employed about 80 people. What would the personnel situation of a LIGO be after it is constructed and operating? Would there be any significant difference between the two facilities in terms of the technical support infrastructure needed near the site?**

The LIGO would require few to operate. One estimate is that about 8 to 10 personnel would be needed for daily operations. Even this number may be high because it is very important that noise due to ground movement be kept at extremely low levels. (See Background Section on LIGO). The presence of a few people and associated equipment may create too much ground noise, and the entire operation may need to be operated remotely. The low ground noise requirement as well as limited research dollars also mean that the other radio telescopes at Green Bank, the 140 foot instrument and the 85 foot interferometer operated by the Navy, are likely to be shut down if the LIGO is built there. In addition, it is possible that services provided for local areas by Green Bank -- such as fire and ambulance service -- would have to be discontinued.

If the 300 foot telescope is not replaced, however, the number of personnel located at Green Bank is also likely to drop significantly. The 140 foot telescope, which, as noted in the background section below, is deteriorating, may be shifted to remote operation for the rest of its useful life. Many researchers believe that the Green Bank observatory would not survive with only the 140 foot telescope. There are two other radio telescopes comparable in size in the United States, and budget pressures may dictate closing the instrument in Green Bank. As its use as an astronomical observatory drops, so would the need for support staff for the entire Green Bank complex. A related concern is the potential breakup of the community operating the Green Bank facility. It is an innovative group, and much of the value of the 300 foot telescope came through the expertise of the scientific and technical support staff. Without a replacement, there would be a loss of a critical mass of trained people.

2. **The discovery of new astronomical objects such as the pulsar in the Crab nebula, brought much attention to Green Bank. Given the nature of the LIGO, would similar or greater scientific prestige accrue to West Virginia should the LIGO detect gravitational waves?**

The detection of gravitational waves by the LIGO would result in substantial scientific prestige for the research team and, at the time of discovery, probably for the site. Such a discovery likely will receive a Nobel Prize in Physics. The absence of any detection, however, would probably result in a series of scholarly papers discussing detection limits. These papers likely would be of only moderate interest to scientists unless they could be used to show that gravitational waves from a stellar event do not exist when such a wave was predicted by theory. The capability of verifying that waves do not exist, however, is far from assured since there is still uncertainty about the theoretical estimates of the strength and wavelength of expected gravitational waves. Such proof also would first require the discovery of these events by optical or radio telescopes.

A further consideration is how the "prestige" of an observation would be allocated. With two detectors apparently required at widely separated locations, (see Background Section) and the research teams located at still other centers -- Caltech and MIT -- it is not obvious that either location of the LIGO detectors would receive much attention in the event of a discovery.

A 100 meter radio telescope, however, is likely to result in many important if not fundamental scientific findings. The history of the 300 foot instrument and the scientific objectives of the proposed 100 meter replacement telescope (see Background Section) are such as to ensure the production of a consistent rate of findings about the structure, origin and dynamics of the universe. One researcher estimated about 100 noteworthy research papers per year could be produced by a new, 100 meter instrument. An important reason for this is the existence of the radio quiet zone which helps to meet the low noise requirements for making such observations. A 100 meter radio telescope located in such a zone would be unique among radio astronomy facilities.

Note how NSF documentation ignored NRQZ,

As a result, a new, 100 meter telescope at Green Bank is likely to keep that location in the scientific forefront for several years, although spectacular discoveries, such as the pulsar found in the Crab nebula in 1968 by the Green Bank telescope may be much less likely. The LIGO, on the other hand, does offer the potential for a high consequence discovery that would rank as one of the most important in 20th Century physics. Such a discovery would be a single event, however, and the probability exists that nothing of major importance will take place.

3. **What would be lost to astronomy if there is no replacement for the 300-foot telescope of any kind for the next 10 to 15 years? Can all or part of that loss be made up with existing facilities elsewhere?**

Even before the loss of the 300 foot telescope, the radio astronomy community, as described in the background section below, put together several proposals for a new, fully tracking instrument in the 100 meter size range. With the loss of the Green Bank instrument, the community as a whole feels that a new, 100 meter, fully tracking instrument should have the highest priority for funding of new radio astronomy facilities. Many call the loss of the 300 foot telescope a severe blow for radio astronomy. The only comparable instrument is in West Germany and the low frequency radio interference near it is so great that West German astronomers have come to Green Bank.

There is a larger telescope than the 300 foot at Green Bank, the 210 meter (700 foot) instrument at Arecibo in Puerto Rico. That telescope, however, has no capability to move independently of the rotation of the earth since it was constructed by digging a shell in the ground. Even though it is more sensitive because of its larger collecting area, the Arecibo telescope covers a much smaller portion of the sky than was possible with the 300 foot telescope, and the latter could perform projects that were not possible at Arecibo. The proposed 100 meter replacement with full tracking capability would be able to cover an even bigger fraction of the sky, nearly three times as much as Arecibo. When the 300 foot telescope was in operation, radio astronomers used both depending on which was optimum for the particular project. They did not duplicate each other and the same would be true for the 100 meter replacement. Radio telescopes are not built to do the same thing so the 300 foot instrument was unique as would be the proposed 100 meter replacement.

A particularly important feature of the 300 foot telescope was its location in a radio quiet zone. Green Bank is the only observatory in a truly radio quiet area and there is unlikely to be another such zone. Pressure exists from radio and TV broadcast interests, and from mobile radio telephone interests to reduce or eliminate the Green Bank zone. Such pressure is likely to increase if the 300 foot telescope is not replaced in a timely manner.

There are some radio astronomers in the United States who feel that replacement of the Green Bank 300 foot telescope should not be the highest priority in this time of very limited funds for radio astronomy. Some believe an instrument capable of receiving very short wavelength signals -- the millimeter array -- should be built first while others would rather put the money into enhancing the very large baseline array (VLBA). It should be noted that many astronomers believe that a new 100 meter radio telescope, as part of the VLBA, would also enhance the latter's capability. In general, however, the Nation's radio astronomers desire a large replacement telescope. While some of the lost capability resulting from the 300 foot telescope's collapse could be made up by clever use of existing facilities, there is, nevertheless, a substantial void in radio astronomy without that telescope.

100 m does this!

Time NSF/Bloch to address this,

4. **The 300-foot telescope was used by a large number of scientists for a wide variety of astronomical research over the last 25 years. The replacement telescope promises even more opportunities for such users if built. How would the LIGO compare?**

The LIGO could be a facility which could be used by a number of researchers if it is successful in detecting gravitational waves and if detection leads to the ability to determine features of the stellar sources of those waves. Meeting these conditions is rather uncertain at this time. First of all, the frequency of stellar events which could produce gravitational waves of significant strength -- pulsars, galaxy or black hole formation, etc. -- be high enough to allow an observation rate sufficient to obtain useful data from these events to characterize them. While most astronomers believe that stellar events which would produce gravitational waves are quite common in the universe, there is much less certainty about how many, if any, of these events could be detected. If an LIGO could only detect events occurring in our galaxy, for example, the instrument would find little use since such events are quite rare. Currently some researchers believe that detection of any event is unlikely. It should be noted that attempts to detect gravitational waves have been going on for nearly 20 years -- using metal bar detector technology -- with no success to date. Such instruments inherently are not capable of reaching the sensitivity limits of a laser interferometer, however, which is the rationale for developing the LIGO.

If the LIGO is successful at detecting gravitational waves, there still remains much work before it could become a practical astronomical observatory. There has been considerable theoretical work in determining the wavelength and magnitude of waves coming from various sources, although uncertainty about these quantities still exists. Verification of these predictions, once waves are detected, and the subsequent calibration of the LIGO is likely to take several years. In order to verify the source of gravitational waves, parallel observations by optical or radio telescopes probably will be needed. While this could occur without rebuilding the 300 foot radio telescope, the existence of another instrument in that size range with full tracking capabilities could aid such confirming observations. Further, significant modifications to the initial LIGO configuration would be needed to expand the range of wavelengths of gravitational waves that could be measured, although such modifications would be straightforward.

As a result of the uncertainty of detection and the time required to develop gravitational wave astronomy if detection were successful, it may be several years, if not longer, before the LIGO could be considered a user facility in a manner similar to a new 100 meter radio telescope. In the meantime the latter would find considerable use, certainly as much as the former 300 foot telescope. That instrument was widely used by astronomers from all over the world. Over 1000 astronomers and graduate students from universities in the United States alone used the telescope over the last 25 years. And, in one recent case, it was being used by four astronomers from Brazil, three from Australia, and three from the United States as well as four graduate students.

**5. Which instrument offers the greater potential for including West Virginia University in collaborative research?**

Currently there is no direct collaboration between the radio telescope and the West Virginia University although there are proposals for the use of the complex as a teaching site for West Virginia University students. A number of students have worked with computer personnel at the Green Bank facility, and more computer linkages are being set up. Whether West Virginia University graduate students and faculty eventually become users of any radio telescope located at Green Bank depends on the establishment of a radio astronomy program at the University. Such an event is more likely than the introduction of a comparable program to make use of an LIGO operating at Green Bank. As described in issue four, there are formidable obstacles to making an LIGO a user facility similar to a radio telescope. The West Virginia University is not involved with the proposed gravitational wave experiment, and the uncertainty of developing the LIGO into an observatory for a variety of users makes it unlikely that the University would want to set up a gravity program any time soon.

It should also be noted that many school children from throughout the state of West Virginia have visited Green Bank. Further, during the last two summers, Green Bank ran teacher training institutes, and the facility has been a popular tourist attraction with approximately 20,000 visitors per year. Duplication of these activities with an LIGO is unlikely because of the need to restrict human traffic to reduce ground noise, and because an LIGO would not present the teaching opportunities that a radio telescope does. The LIGO is a frontier scientific experiment which, even if successful in detecting gravitational waves, would not yield the kind of information of significant use as a teaching tool in the near future.

## SCIENTIFIC BACKGOUND

### RADIO TELESCOPE PROPOSAL

### 1. Radio Astronomy Background

All stellar objects emit electromagnetic radiation. The visible portion of the electromagnetic spectrum (optical frequencies) has been observed since the dawn of the human species. The invention of the telescope in the early 17th century greatly expanded mankind's capabilities in optical astronomy. Advances in optical telescopes continued from the first small instruments to the large telescopes of today including the 200 inch telescope on Mt. Palomar and the multi-mirror telescope (equivalent to a 273 inch mirror) on Mt. Hopkins in Arizona. The next large optical telescope is the Hubble Space Telescope which is due to be launched in 1992 aboard the space shuttle. Its launch has been delayed several years due to the Challenger accident.

In 1931, a researcher at Bell Labs discovered that stellar objects also emit electromagnetic radiation in the radio frequency portion of the spectrum. This portion is so named because radio and television broadcasts occur at these frequencies. It was soon clear that information about stellar objects could be obtained with instruments that received these radio emissions just as using optical telescopes could obtain information by gathering visible radiation from these objects. Further, it was discovered that many stellar objects existed which gave off large quantities of radio emissions but little or no visible radiation. These discoveries gave rise to an entire, new branch of astronomy known as radio astronomy.

In the 1950s, radio astronomy came of age with the construction of the radio telescope at Jodrell Bank near Manchester, England. In the United States in 1956, the National Radio Astronomy Observatory (NRAO) was organized with support from the National Science Foundation. The organization is managed by a consortium of nine eastern universities. The NRAO picked the site of Green Bank, West Virginia as the location for its first radio telescope, and in 1962, a 300 foot diameter radio telescope was completed. This instrument was followed in 1965 by a 140 foot diameter telescope at the same site.

Beginning of rad astro in U.S. Don't cut off the roots of the science.

### 2. The Green Bank 300 foot Telescope

The 300 foot telescope was built quickly and inexpensively. As a result, it was only capable of changing its orientation in one direction, its elevation. Changing orientation in the other plane, the azimuth, was accomplished as the Earth rotated. This limitation did not preclude the 300 foot from being a very useful instrument. The telescope was designed to observe radio emissions at frequencies which include that characteristic of hydrogen, the most common element in the universe.[1] Measurement of the 21 cm hydrogen emission wavelength allows astronomers to map regions of space that cannot be seen by optical telescopes, and to study the dynamics of stellar objects.

The 300 foot telescope was very productive over its life. It was one of the most powerful radio telescopes in the world and was the largest in the United States capable of surveying most of the Northern sky. The telescope was used to make detailed surveys of stellar radio sources including galaxies outside our own, and objects such as pulsars and gravitational lenses. These surveys are currently the most complete and detailed available to astronomers, and form the basis of more intensive exploration by optical telescopes when possible and by radio telescope assemblies which have higher resolution than the 300 foot. The latter include the very large array (VLA) in New Mexico and the very large baseline interferometer (VLBA) which consists of telescopes throughout the world including the 140 foot telescope at Green Bank.

The most notable discovery of the 300 foot telescope was proof of the existence of a pulsar in the Crab nebula. This discovery proved that pulsars -- sources of intense, pulsating radiation -- result from the collapse of the core of a star after it has exploded to form a supernova. By measuring 21 cm radiation, the 300 foot telescope proved to be a very good instrument for determining the shape and size of our own galaxy. In the same way, the 300 foot was used extensively to determine the distribution, size and motion of other galaxies in the universe.

3. <u>The Replacement Proposal</u>

In December 1988, a group of 56 astronomers gathered at Green Bank to discuss the consequences of the collapse of the 300 foot telescope. The result of that meeting was the initial stage of a proposal to replace the destroyed instrument. The draft report[2] notes that prior to the collapse, several studies had been undertaken that pointed out the need for a "large, general purpose radio telescope" which could detect radiation down to one cm wavelength, and which would have a diameter of at least 330 feet (100 meters). This instrument was recommended as a supplement to the 300 foot at Green Bank. Other reports have indicated that radio astronomy in the United States is currently facing severe difficulties because of deferred maintenance on many

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[1] The wavelength of this emission is 21 centimeters (cm) and radio telescopes are characterized by the wavelengths they can receive. The lower wavelength limit is determined by the smoothness of the telescope's surface. Before its collapse, the 300 foot telescope could receive wavelengths down to 6 cm.

[2] Scientific Considerations for the Design of a Replacement for the 300-ft Radio Telescope, Draft Proceedings of a Green Bank Workshop, National Radio Astronomy Observatory, December 1988.

of its telescopes. For example, the 140 foot instrument at Green Bank has an obsolete equatorial mounting, and its surface is suffering excessive deformations because of age. Therefore, the loss of the 300 foot telescope exacerbates what many believe was an already serious problem in United States radio astronomy.

With this background, the committee at Green Bank proposed a telescope which would be significantly more capable than the one it would replace. The tentative design calls for a 100 meter telescope which is capable of measuring radio emissions at wavelengths as short as 1 to 2 cm. The proposed telescope would be fully tracking, that is be capable of moving both in altitude and in azimuth. The proposed telescope should also incorporate design features that would keep interference from man made radio frequency sources to a minimum. Because Green Bank is a National Radio Quiet Zone, location of the new instrument there would be a "distinct advantage" according to the proposal. No other sites were considered in the draft report. Indeed, one of the more serious limitations to radio astronomy is the existence of unwanted radio noise just as light pollution has severely limited the possible locations for new optical telescopes. As indicated in the draft report, the cost of this proposed radio telescope is estimated to be 50 to 70 million dollars, and it could be operating four years after the start of engineering design. There would be many scientific benefits of a 100 meter, 1 cm wavelength radio telescope. It would expand extensively on the capabilities of the former 300-foot telescope. The full tracking feature and high sensitivity would allow much greater coverage for surveying radio sources, expanding the search for new galaxies and pulsars. The extended tracking range of the proposed instrument could lead to the discovery of more pulsars as well as more detailed studies of the physics of pulsars. This information along with a better picture of the distribution of pulsars which would be possible with the proposed telescope, is quite important in understanding the evolution of stars and the universe.

With the proposed telescope, the acquisition of hydrogen emission data from stellar sources beyond our galaxy would be greatly enhanced. This information would increase our understanding of the large scale structure of the universe, the structure of and evolution of galaxies, and the structure of galaxies soon after their formation. The latter is possible because radio signals which can now be received from very distant galaxies were emitted several billion years ago when the universe was in its early stages of formation. The expanded range of wavelength detection would allow extended studies of extragalactic molecular composition which could also help achieve a better understanding of the evolution of galaxies.

The proposed instrument would also expand the mapping of radio sources which was a major responsibility of the former telescope. The increased sensitivity could yield the discovery of new stellar radio sources which, in turn, would provide additional targets for more detailed study by the VLA and VLBA. In addition, the proposed 100 meter telescope, if made part of the

VLBA, could greatly enhance its capability to study very weak stellar objects.[3] Also, the new instrument could be used to support space based radio telescopes and other space probes. Linking space telescopes to full tracking, ground based instruments greatly expands the sensitivity of the space system in much the same way the VLA and VLBA work on the ground. Other benefits of a new 100 meter telescope would be the possibility of more detailed study of molecular radio sources in our own solar system including those of comets that orbit the sun, of solar radio emissions to better understand the properties and behavior of the sun, and of our galaxy in terms of its structure and dynamics. These possibilities are brought about by the greater sensitivity the new instrument would have, its full tracking capabilities and extended wavelength sensitivity.

## GRAVITATIONAL OBSERVATORY PROPOSAL

### 1. Gravitational Waves

Gravity is the force that acts between all objects with mass. The magnitude of the force between two objects depends on the size of the objects' mass, a gravitational constant first calculated by Newton, and is inversely proportional to the square of the distance between the two objects. Gravity is the force which holds us on the planet, holds the planets in orbit around the sun and acts between all stellar bodies. The General Theory of Relativity developed by Albert Einstein in 1916, predicted that the force of gravity could manifest itself in the form of radiation -- a gravitational wave -- if the mass of an object were to suddenly change either due to acceleration or to a loss of material such as would occur if it exploded. In this manner, gravitational waves would behave similar to more familiar electromagnetic waves.

Gravitational waves, however, are much weaker than electromagnetic waves. A gravitational wave emitted by an electron would be more than 40 orders of magnitude (powers of ten) weaker that an electromagnetic wave coming from the same electron. Another difference is that gravity does not act at a specific point like electromagnetic waves do. For example, if a gravitational wave were to act on a test object, it would also act on the observation instrument in exactly the same way, thus making it impossible to measure the reaction of the wave on the test object.

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[3] The VLBA, by electronically linking a number of widely separated radio telescopes, is able to simulate a single telescope with an aperature equivalent to that separation distance. These distances, in the case of the VLBA, can be several thousand kilometers giving the VLBA a much greater sensitivity than any single radio telescope could have.

## 2. Detection of Gravitational Waves

Because of their importance for further verification of the theory of relativity and the prospect they hold for further study of stellar objects and phenomena, detection of gravitational waves would be a significant scientific achievement. Thus far, such attempts have failed, although indirect observation has occurred. The two characteristics of gravitational waves, their weakness and the absence of action at a point, put severe constraints on any attempt to detect them.

It is not feasible to detect gravitational waves produced by objects in the laboratory. A 500 ton steel bar rotating at a speed which would cause the bar to tear apart would generate a signal about 20 orders of magnitude too weak to be detected by instruments that are currently being proposed for detection of such waves. Only stellar sources are likely to produce waves that could be detected. These include, among others, binary stars (a two star system in which the two stars rotate around each other), neutron stars (pulsars) which result during the collapse of a star, supernova, the formation of galaxies, and black hole formation. The key aspect is a massive change in or acceleration of gravitational mass.

Indeed, the first evidence of the existence of gravitational waves occurred in 1974 while observing a binary star system. Careful measurements of the change in rotation period of the pulsars about one another showed that the pulsars were losing energy and would eventually collide. The rate of energy loss corresponded quite closely to that expected if the mechanism for energy loss was emission of gravitational waves. While clear evidence, no direct detection of the wave was possible, however, at the time.

Even from such massive sources, the waves will be very weak. The energy from a gravitational wave from a binary pulsar, for example, would change the separation of two test masses by $10^{-21}$ meters per meter of initial separation. This distance is one millionth the diameter of a proton. Waves from other stellar sources are predicted to give equivalent displacements. The first attempts to measure such waves used single, massive metal bars. The bars were carefully designed to be responsive to a gravitational wave of a selected frequency. If a wave passed through the bar, it would vibrate due to the force of the wave. The vibration could be measured by very sensitive strain gauges surrounding the bar. By careful suspension and the shielding against other sources of vibration, extremely small strains were able to be detected. The detection limit, however, is still about 1000 times too small to detect gravitational waves, and no signals have been detected by this method. Even though more sensitive bars are possible, most researchers now feel that this path will not lead to detection.

A point about this experiment that holds for any kind of detection method is the need for a pair of detectors separated by a long distance, on the order of a few thousand miles. This separation is to ensure that any signal picked up is not due to local disturbances. Since gravitational waves from stellar objects would bathe the entire earth and not appear just at a point, detection would occur at both locations nearly simultaneously. A local disturbance or false electronic signal, however, is very unlikely to show up at both places at the same time.

Another potential detection instrument is a laser interferometer. The relative displacement of two masses due to a gravitational wave will show up as a change in the light pattern formed by the superposition of two laser beams, each reflecting off one of the masses separated in space. The shift in this pattern, called an interference pattern, due to a given change of separation between the masses, grows as the length of the initial separation distance increases. In addition, the sensitivity of the detector depends on the total length of the path travelled by the laser light. Since this length is adjustable by making the beam reflect back and forth many times between mirrors, a very long path can be built in a reasonably sized instrument.

The instrument proposed to detect gravitational waves is a laser interferometer called a laser interferometer gravitational observatory (LIGO). A proposal to build one has been made jointly by California Institute of Technology and the Massachusetts Institute of Technology; the National Science Foundation has tentatively committed to the project. The NSF has asked for level funding in the FY1990 budget request for continued R&D on the detector, but has not yet requested funding for construction of the LIGO. The proposed LIGO is a large scale version of an instrument currently operating at Caltech, and is expected to cost about 60 million dollars. The Caltech interferometer has the test masses separated by an optical path of 40 meters. While it is quite sensitive, it is unlikely to detect gravitational waves from any but the largest and closest stellar sources. For example, it is possible that the Caltech instrument could detect waves from stellar explosions that occur within our own galaxy. Such events are rather infrequent, however -- they may occur about once every 30 years or be as rare as every 500 years -- ruling out this instrument as a practical detector. The proposed LIGO will have the test masses separated by four kilometers, a factor of 100 greater than the Caltech instrument, which it is hoped would allow detection of waves coming from stellar events that are expected to occur several times a year.

One of the major problems in detecting gravitational waves is the presence of background noise. With signals as weak as these, even the presence of air molecules bouncing off the masses would cause displacements much bigger than that of a wave. Thus, the test masses must be housed in a nearly perfect vacuum, and the 4 km long chambers separating the masses will have to be evacuated. In addition, all other sources of noise -- such as very low amplitude, background ground vibrations (seismic) and thermal excitation of the test masses themselves -- must be reduced below the signal level expected for a wave. Careful design and suspension of the test masses can damp out these vibrations. Also, as stated, building two identical interferometers and separating them by a few thousand miles will virtually eliminate false measurements due to seismic noise which is very unlikely to affect the two stations at the same time. If construction funds for the LIGO are requested and if they are granted by the Congress, one of the pair of interferometers making up the LIGO would be located southern California. The other, currently, is slated to be located in Maine. This latter is the unit proposed for Green Bank.

## 3. Scientific Objective

The primary objective of the experiment, of course, is the first direct detection of gravitational waves. If such detection is associated with a visual observation, such as would occur if the gravitational waves came from a supernova, the speed of the gravitational waves could be measured by noting the relative time of arrival of the two events. The next piece of useful information to obtain would be the direction from which the wave came. In order to do that, three detectors would be needed. While a third detector is not part of the current proposal, two projects are currently being proposed in Europe that could provide that third leg.

Because the wavelength of these waves is characteristic of their source, however, observation of gravitational waves could lead to a new realm of astronomy, making an LIGO truly an astronomical observatory. Gravitational waves can pass through objects that do not permit electromagnetic radiation to escape. For example, gravitational radiation from inside a collapsing star could, in principle, be detected while light and radio waves from that region would be trapped by the surrounding matter. The formation of a black hole also could be observed in principal by monitoring the gravitational waves that are generated during its formation. Electromagnetic radiation, on the other hand, does not escape from a black hole so its direct observation by standard astronomical means is not possible. Therefore, if it turns out to be feasible to observe gravitational waves of varying frequencies and intensities in a reasonably routine manner, a powerful new astronomical tool will have been created.

The extreme weakness of these waves as well as certain characteristics of the LIGO, however, makes achievement of such "routine" observation far from certain. The optical path of the LIGO must bear some quantitative relationship to the wavelength of the wave to be observed. While an LIGO would be adjustable, the current range of wavelengths that it could operate at may be many orders of magnitude smaller than those generated by stellar events. It may be necessary to build several interferometers at one site to hope to capture any useful information. Indeed, the current proposal is being built to house several interferometers of different path lengths for just such a purpose, although the instrument will not have all of these installed at first.

The LIGO is a high risk experiment. If successful just in detecting gravitational waves, a major step in physics will have taken place. Doing so, however, will require a substantial advance in the limits of current technology.