NATIONAL SCIENCE FOUNDATION

WASHINGTON, D.C. 20550

*February 28, 1989*

OFFICE OF THE
ASSISTANT DIRECTOR
FOR MATHEMATICAL AND
PHYSICAL SCIENCES

## MEMORANDUM FOR ERICH BLOCH

From: Richard Nicholson

Subj: Recommendation for Construction of LIGO

You asked for my recommendation as to the priority of LIGO versus replacement of the collapsed radio telescope at Green Bank.

There is no doubt that a strong scientific justification exists for each of these projects, and in an unconstrained system I could be enthusiastic about going ahead with both of them. However, in terms of priorities, I believe a significantly stronger case exists for LIGO, and therefore it has my unqualified recommendation for the highest priority.

Some of my reasons for this recommendation are contained in the remainder of this memorandum.

### LIGO

Detecting gravitational radiation has been an important scientific goal since Einstein developed the General Theory of Relativity early in this century. Since the effect is very weak, detection was long assumed to be impossible. However, with advances in technology during the past 15 years, particularly in lasers and super-reflective mirrors, it now appears that gravitational radiation could be observed with LIGO.

Now radiation has been detected with a radio telescope.

To detect gradational radiation would open an entirely new window in physics and on the universe (because the origin of the phenomenon is physically different from electromagnetic radiation). Many think the discovery would be worthy of a Nobel prize. While today it cannot be called astronomy, if successful, LIGO probably would be the "telescope" of the next century.

Taylor's discovery
Penzias/Wilson
Ryle/Hewish
[illegible] medals
Heineman Prize

NSF is the only agency that supports basic research in gravitational physics, and has been solely responsible for the R&D on the LIGO project for the past sixteen years. This research has been spectacularly innovative and successful, including the construction of a prototype (a 1/100-scale version of LIGO at Caltech). Over this time the project has been extensively reviewed and evaluated. This review has included numerous project peer reviews, as well as reviews by the National Science Board, the NSF Physics Advisory Committee, and the National Academy of Sciences (the 1986 Physics Survey known as the "Brinkman" Report). In each case the project has received an unqualified endorsement, and in the latter two cases it was rated top priority. It also has been endorsed by an International Workshop (1986) that involved physicists from a variety of subfields of physics, not just gravitational physics, and by the International Society for General Relativity (1986). A Project Development Plan was approved by the National Science Board in 1984, and the Conceptual design stage is nearing completion.

In short, LIGO is a thoroughly researched, reviewed, and widely endorsed project. It could open an entirely new window in science and thus it has the potential of producing many unexpected and profound discoveries. It represents the very essence of basic research and the mission of the NSF. In addition, because it involves extremely creative scientists with a track record of pushing measurement technology to its very limits, it seems very likely, even certain, that LIGO will produce many practical spin-offs.

Pulsar clocks.

Radio Astronomy's case laid out by Bob Brown

## Radio Telescope

see 1987 NOF referee's reports

Of course, we only began discussing this project following the collapse of the 300-foot telescope at Green Bank last Fall, and therefore it has nothing like the 16-year history of LIGO with which to compare. Nevertheless, it is clear that, both scientifically and technologically, LIGO is revolutionary where the replacement antenna is evolutionary.

Kerr's "new discovery"? Rad astro is revolutionary! When did revolution end? Grav. Lenses. Filaments + Voids.

The collapsed antenna had been a workhorse, especially useful in large surveys, and had over the years provided a great deal of useful scientific data. Nevertheless, in a priority sense, this antenna had recently been placed in category "C" by a distinguished committee (the "Langenberg" report) established by NSF to review and set priorities for facilities in radio astronomy.

Langenberg classifies telescopes by age (not wavelength) — meant 300 ft was about to fall down,

It's a statistic to show what NSF's Langenberg approach has done.

In the short time following the collapse, a good scientific justification has been developed by the U.S. radio astronomy community for replacing the collapsed telescope with a 100-meter class, high performance radio telescope. The proposed telescope would have several new features, such as the ability to work at millimeter wavelengths and to observe the galactic center, making it to a certain extent a replacement in name only.

Yes, but would you advocate ignoring 30 yrs of technical development since 300 ft began?

Severe distortion

Despite the scientific justification and the added capability, I see several *relative* disadvantages in terms of putting this project at the highest priority. First, while millimeter work is a high priority, the location at Green Bank is less than ideal due to atmospheric conditions. Thus, the scientists estimate that at best there would only be about 60 days per year when the weather conditions would permit full use of the higher performance of the proposed telescope, raising questions of cost-effectiveness.

This is almost free!!

GB Site: (1) Colossally un-ideal for LIGO.
(2) NRQZ. You must mention this. GB perfect.

Another concern has to do with overall priorities for the whole field of astronomy, including optical astronomy. New radio astronomy facilities have occupied a high priority at NSF for the past twenty years, starting with construction of the VLA in the seventies, and continuing with the construction of the VLBA in the eighties. To now construct another radio facility in the nineties, would most likely preclude any significant project for optical astronomy, given any realistic budget projections. This would therefore amount to nearly 30 years of NSF focusing on radio astronomy to the likely detriment of optical astronomy. Thus, in the interest of a balanced national program, I believe NSF should await the next "decade survey" before starting a major construction project in radio astronomy. Stalling tactic.

Balanced national programs;
300 ft collapsed. ⟹ Balance now disturbed.
~~Not replace~~ Must replace to restore astro's balance.

No

DRAFT

March 1, 1989

LASER INTERFEROMETRIC GRAVITATIONAL OBSERVATORY (LIGO)

After much consideration of the various options, NSF has concluded that LIGO represents an important scientific opportunity that should go forward at this time. LIGO is a chance for the National Science Foundation to respond quickly to a unique scientific opportunity to support highly innovative and forefront research to push back the frontiers of knowledge.

## PROJECT DESCRIPTION

Rad astro + Einstein: Grav. radiation, Neutron stars, Black holes, Grav lenses, Largescale distr of matter & energy

LIGO will be a major scientific research facility whose purpose is to detect and measure gravitational waves. Gravitational waves are something scientists have wanted to observe since Einstein first predicted their existence, but only recently has the technology been developed to make this possible. The reason they are so difficult to detect is that the effect is very small; it is necessary to detect movements of less than the diameter of a single atom. Gravity waves will provide a fundamentally new way to view the universe. This development will be at least as revolutionary as radio and X-ray telescopes. LIGO will see further away, earlier in time, and penetrate deeper into space and astronomical systems than anything ever conceived before.

Not deeper than 3K background

A LIGO site would consist of a control building with two large vacuum tunnels (above ground) at roughly right angles and 4 kilometers (2.5 miles) long. Two essentially identical LIGO sites are required "by the physics" of the observation. The sites must be separated by at least 1000 miles. LIGO's vacuum tunnels and control room would house some of the world's most technologically advanced lasers, mirrors, optics, and computers. The facility would operate over the long term, both as a basic research center for continually improving and developing technology, and also as an "observatory" to which visiting scientists from around the world would come to make observations.

## CURRENT STATUS

Compared with radio astronomy's years of development.

LIGO has undergone 16 years of prototype development by scientists in the U.S. and Europe. Since FY 1985 NSF has provided about $12M to support LIGO prototype development and planning. Conceptual design is nearly complete. Construction techniques and cost estimates have been developed by Stone and Webster, A.D. Little, and JPL working with scientists at MIT and Caltech. A construction proposal will be submitted to NSF before the end of this summer. Same timing as radio telescope

LIGO has been thoroughly reviewed and prioritized by the U.S. and international scientific community. It has been endorsed by the

300 ft telescope had repeatedly been thoroughly reviewed & prioritized.

National Academy of Sciences in the "Brinkman" report and the NSF Physics Advisory Committee as the highest priority project in ground based gravitational research.

The National Science Board approved the project development plan in 1984 and has regularly received briefings on the project since that time--most recently in May 1988. These actions have prepared the National Science Board to review the forthcoming construction proposal.

The Office of Management and Budget has regularly supported the research and development budget requests for LIGO over the last several years and will be receptive to project construction and implementation.

As with other NSF projects, no specific authorization legislation is required. Section 3(a) of the The Foundation's organic act (42 U.S.C. Sec 1862) authorizes the Foundation:

> to initiate and support basic scientific research and programs to strengthen research potential...at all levels in the mathematical, physical...and other sciences...by making contracts or other arrangements (including grants, loans, and other forms of assistance) to support such scientific...activities.

The current five year authorization (P.L. 100-570) also provides sufficient authorization for project implementation, provided funds for the project are appropriated.

## SCIENTIFIC OPPORTUNITIES

LIGO represents a new tool for fundamental physics and astronomy research, with capabilities far surpassing other current instruments. It will permit the first detection of gravitational radiation and exploration of its properties (velocity, polarization, etc.). The work that could be accomplished with LIGO is of a caliber that could likely lead to a Nobel Prize. Gravity wave observations would open a new window to the universe that is radically different from cosmic-ray, radio or optical astronomy. It could also dramatically enhance the study of astronomical objects such as black holes, supernovae, pulsars, galactic nuclei, and the early universe. LIGO will both be a long term observatory as well as a research and development facility.

Taylor's pulsar decay

Rad Astro Prizes

eg Picking radio astronomy's inventory

## INTERNATIONAL IMPLICATIONS

Strong groups of capable scientists already exist in Western Europe. A new group to pursue gravity wave detection has also been created in Japan. An international agreement has been reached to collaborate for maximum payoff for both physics and astronomy in the coming decades. The U.S. remains, however, the world leader in this area with the ideas and creativity; the

Abt's sad story for astronomy.

highest quality of scientists; and progress toward implementing construction and operation of such a facility. Construction will enhance U.S. leadership.

## COST ESTIMATES, SCHEDULE AND ECONOMIC IMPACTS

Construction techniques and cost estimates, at various levels of detail, have been examined at over 150 sites within the U.S. Since 1983. Total cost of design and construction of the first LIGO site is estimated at appoximately $75M. The tentative schedule and initial cost estimates for LIGO are shown below:

Cost escalation: Project once needed $100 M for 2 LIGOs.

FY 1989, $4.8M to (in addition to the $4M already in the current year's plan) for engineering design studies, site surveys, equipment, and staff.

FY 1990, $6.8M to (in addition to the $4.2M already included in the FY 1990 request) for engineering design studies, equipment, and staff.

FY 1991, $15-25M to begin first site construction of which $3-12M is estimated for earthwork. FY 1991 budget not yet formulated.

Is this where GB cost-deltas are finessed?

FY 1992, $15-25M to continue first site construction of which $3-12M is estimated for earthwork. ($5M to begin construction at second site)

FY 1993, $5M to complete first site construction and begin installation of receivers at first site. ($15-20M to continue construction at second site)

FY 1994, $5M to complete installation of receivers at first site and begin operation at approximately $2.1M per year. (complete construction at second site $10-20M)

FY 1995, ($10M to install receivers and begin operation at second site at approximately $2.4M per year.) Operational site at first site continues at $2M per year.

Permanent staffing of the first LIGO facility would require approximately 20 persons; 10 people in full time residence dedicated to operations (site manager, computer programmer, electronics technician, mechanical/vacuum technician, plant maintenance technician, and 5 operators) plus 10 local people working under contract to maintain mechanical equipment. Researchers from around the world will want to use this world class facility. Scientists and engineers from nearby universities would have the opportunity to conduct research using LIGO as well as develop high school and collegiate educational activities that include LIGO. Local university personnel could become involved in the ongoing instrumentation R&D activities.

Be serious! Compare with support from WV science teachers.

WVU has addressed this.

## ESTIMATED COSTS

Estimates

### REPLACEMENT RADIO TELESCOPE: GREENBANK

Preliminary Design..........................................0.5
Design Contract.............................................2.7
Construction ...............................................53.7
Project Management, Instrumentation and Contingency..18.7
Total Estimated Cost........................................75.0

FY89 $4m
FY90 $2m
FY91 $25m
FY92 $20m
FY93 $15m
FY94 $10m

Annual Operating Cost Estimate: ~~increment?~~............ 0.3 ~~this can't be~~

Est Annual Operating Costs of Existing Radio Observatory without replacement instrument..................... 3.0

Total Est Annual Operating Costs of Existing Radio Observatory with 300 ft replacement telescope................ 3.3

### LIGO: GREENBANK

Design, Site Survey, Related Equipment...............19.8
Construction................................................50.0
Installation of Receivers................................. 5.0
Total Estimated Cost........................................74.0

Annual Operating Cost Estimate........................ 2.1

Total Est Annual Operating Costs of Existing Radio Observatory with LIGO...................................... 5.1

No one has mentioned GB's cost deltas. Very dishonest!

March 1, 1989

What makes anyone think existing radio obs. will ~~exist~~ persist?

LIGO not big enough to form infrastructure on which other activities can be built.

But radio obs observatory big enough that appending ~~something~~ LIGO to RA's infrastructure at least conceivable

Possible scenario:
(1) No new radio telescope.
(2) ∴ NRAO withers away in WV.
(3) Now no justification for LIGO in GB.
(4) ∴ WV gets neither.

## BACKGROUND INFORMATION FOR SENATORS BYRD AND ROCKEFELLER REGARDING THE LIGO PROJECT: GREENBANK

Scientifically, LIGO is an extremely prestigious and exciting project (of Nobel Prize caliber) that would ensure the LIGO sites with a prominent position on the World's scientific map.

Following the two year construction phase, LIGO will also be a major research and development effort that will continue for many years. There will never be a time when the sensitivity of the instrument is as good as one wants it. The ongoing research and development effort would be needed to continually improve LIGO's sensitivity. Thus the existing infrastructure of the radio astronomy observatory could form the foundation for a permanent state of the art electronics and laser facility. *Will electronics & laser development be done at CIT & MIT?*

Approximately $50-55M (up to around $25M locally) would be spent during a construction phase at Greenbank for 400 man years during the two year construction phase of the project.

In addition to operational costs spent at Greenbank for radio astronomy (approximately $3.3M in FY 1989), an additional $2.1M per year would be required for LIGO activities when operational (targeted for FY 1994) increasing annual operating support from $3.3M up to $5.1M.

Assuming FY 1989 staffing levels at the radio astronomy observatory, installation of LIGO at Greenbank could increase employment at Greenbank over current levels by about 10-12 positions (If one assumed 8.5 positions were supported by the 300 foot telescope, the requirement of approximately 20 for LIGO operations is projected).

Visiting scientists at the rate of at least 5 per year will be housed at each LIGO site. The number of visiting scientists per year could increase when gravity waves are observed; there will be instant, world-wide interest in the project.

LIGO is estimated to use 1MW of electricity annually at a cost of $350,000 per year.

LIGO will have the potential for important spin offs in the area of stable high power lasers, optical components, and precision measurement technology.

LIGO will enhance insights gathered by observations in space. By combining data from all available sources, correlations between signals will be far more valuable than the separate components in locating the positions of sources and unraveling the complexities in their behavior.

LIGO could help NASA since LIGO's development of stable lasers will be useful for developing high capability communications links to satellites.

# COST CONSIDERATIONS

## LIGO

- Construction techniques and cost estimates studied for various sites since 1983
- Construction $50M, of which $26M spent locally
- Operations $2M/yr

## RADIO TELESCOPE

- Cost estimated with reasonable confidence at $75M, including design, contingency, and instrumentation
- Construction contract $53M (included in $75M TEC) to outside vendor (TIW, RSI, etc.) *who might hire several locals,*

*All erection done here. RSI considered fabrication here.*

# OVERALL PROJECT IMPLEMENTATION SCHEDULE

## LIGO

- 1989: $8.9M Engineering design, equipment, staff, site surveys
- 1990: $10.9M Engineering design, equipment, staff
- 1991: $30M Begin construction at East Coast site
- 1992: $30M Continue construction at East Coast site, initiate West Coast site

*Order has reversed.*

- 1993: $25M Complete construction at East Coast site, continue construction at West Coast site
- 1994: $25M Complete construction at West Coast site, install receivers and begin operations at East Coast site
- 1995: $10-20M Install receivers and begin operations at West Coast site

## RADIO TELESCOPE

- 1989: $4.0M Conceptual and engineering design
- 1990: $1.7M Engineering design (continued)
- 1991: $25.7M Fabrication and site development
- 1992: $17.3M Erection of antenna structure
- 1993: $17.3M Setting panels, outfitting, and testing
- 1994: $9.0M Construction and operations

# INTERNATIONAL IMPLICATIONS

## LIGO

- Part of an international network involving the U.S.A, France, Italy, Great Britain, and West Germany
- Multinational agreement for complimentary investment in receivers and joint technology development

## RADIO TELESCOPE

- Anticipated use as major ground station for space VLBI satellites Radioastron (USSR) and VSOP (Japan)
- Additional to world-wide network of ground-based VLBI stations, including antennas in Europe, Australia, and across the U.S.
- Draws users from entire world: Canada, Mexico, Brazil, England, Spain, Germany, The Netherlands, Sweden

# CURRENT STATUS

## LIGO

- NSB Project Development Plan approved 1984
- Endorsements: NSF Adv. Comm. for Physics (1983)
  NAS Physics Survey (1986)
  Int. Soc. for Gen. Relativity & Grav. (1986)
- 16 years of prototype R&D — This argument used both ways — rad astro old, ∴ unexciting; LIGO new; but here LIGO old tools.
- Conceptual design nearing completion

## RADIO TELESCOPE

- Recommended by Radio Astronomy Panel of "Field Committee"
- U.S. user workshop (Greenbank, West Virginia 1988)
- Uses advanced technology for panels and support system and design for reducing aperature blockage
- Conceptual design recently re-initiated
- May 1987 site visit by AAG NSF referees.

(if anything) Rad Tele conceptual design ahead of LIGO's

EMPLOYMENT IMPACTS

LIGO

- Short term employment for 400 man-years during construction
- Long term operations staff of 20
- 5 FTE visiting scientists This is not what you consider a national center. GB's ~600

RADIO TELESCOPE

- On-site construction crew brought in by contractor ?
- 140' to be mothballed within a few years
- 100-150 on-site users/year
- NRAO presence at Green Bank continues at present levels
  → This won't be true as early as 1990!

LEGISLATIVE REQUIREMENTS

LIGO

- No specific authorization legislation required. NSF Organic Act and current five year authorization act provide sufficient authorization for project implementation, provided adequate resources are appropriated.

RADIO TELESCOPE

- No specific authorization legislation required. NSF Organic Act and current five year authorization act provide sufficient authorization for project implementation, provided adequate resources are appropriated.

o Short term employment for 400 man-years during construction

301/754-7089

## PROJECT DESCRIPTION

LIGO

o First instrument to observe the universe by entirely new medium of gravitational radiation *Ignoring radio astronomy's study*

o Two 4 km "L"-shaped vacuum systems, housing advanced laser detectors *Confined at GB? What if next stage is to add to arms' lengths? How to fit in other polarization at 45°?*

RADIO TELESCOPE

o Fully steerable, 100-meter class aperture, high performance radio telescope, operable to 7mm or ~~better~~ *shorter*

Located in the National Radio Quiet Zone and designed to minimize interference from man made and natural radio signals.

## SCIENTIFIC OPPORTUNITIES

LIGO

o New tool for fundamental physics (and astronomy) research

o ~~First~~ *Second?* detection of gravitational radiation and exploration of its properties (velocity, polarization, etc.)

o Research is of a caliber that could lead to Nobel Prize *Exaggerated hyperbole!*

o Opening of a window to the universe which is radically different from electromagnetic, cosmic-ray, or neutrino astronomy

o Study of astronomical objects such as black holes, supernovae, pulsars, galactic nuclei, compact binaries, and the early universe *This is misplaced, should be under radio telescope*

RADIO TELESCOPE *Ridiculous to abandon rad. research if these are your objects of interest*

o Re[illegible] and upgrade capability for observations at radio wavelengths, with access to center of the Milky Way galaxy

o Studies of structure of the universe, gaseous content of galaxies, solar/stellar phenomena, molecular clouds and star formation, evolution of galaxies, and the solar system *Gravity/Gen. Rel.; Largescale Distr. of Matter + Energy; Origin of Life; Black Hole accretion disks*

o Applications to space- and ground-based very long baseline

Terry Swain

# Questions for National Science Foundation

Independent of construction funding for the Very Long Base Line Array, funding for the radio astronomy has declined. The 1989 budget for operations is slightly less than 1984. Inasmuch as some of the money goes to support VLBA operations, the decline in funding has had an even more adverse impact on the ability of the National Radio Astronomy Observatory to maintain operations, particularly in the face of inflation.

What were the staffing levels at Green Bank in FY 1984 (by function) and what are those staffing levels now?

Staffing Levels at Green Bank

| | 1984 (Dec) | 1989 (Jan) |
|---|---|---|
| Telescope Operations | 18 | 14 |
| Machine Shop & Cryogenics | 15 | 11 |
| Electronics | 23 | 20 |
| Plant Maintenance | 17 | 13 |
| Scientific Services | 12 | 9 |
| Administrative Services | 13 | 8 |
| Fiscal Office | 8 | 5 |
| Research Staff | 3 | 0 |
| Mechanical Engineering | 4 | 0 |
| VLBA Construction | 3 | 4 |
| Total | 116 | 84 |

How much does the FY 1990 budget include for radio astronomy? Of those amounts, how much is dedicated to operations, and construction?

The FY 1990 Request includes funding for two National Astronomy Centers having radio astronomy facilities:

| | | FY 1989 Current Plan | FY 1990 Request |
|---|---|---|---|
| National Astronomy and Ionosphere Center (NAIC) | Operations | $ 6.15M | $ 6.35M |
| National Radio Astronomy Observatory (NRAO) | | $30.11M | $31.21M |
| | Operations | (18.3) | (19.0) |
| | VLBA Construction | (11.8) | (12.2) |

Radio astronomy is supported on research grants as appropriate to the subject matter.

How many staff are associated with the operation of the 140-foot and the 300-foot telescopes (by function).

Green Bank Operations Staff Assignments by Telescope - 1989

300-Foot (reassigned to other duties at Green Bank following collapse)

| | |
|---|---|
| Telescope Supervisor | 1 |
| Operators | 4 — Davis resigned Chestnut to USNO |
| Scientist | 1 |
| Computer Programmer | 1.5 |
| Mechanical | 1 |
| | 8.5 |

140-Foot

| | |
|---|---|
| Telescope Supervisor | 1 |
| Operators | 5 — Now 4. |
| Scientist | 1 |
| Computer Programmer | 1.5 |
| Mechanical | 3 |
| | 11.5 |

| | |
|---|---|
| U.S. Naval Observatory (USNO) | 11 |

Common Green Bank Support*

| | |
|---|---|
| Electronics | 20 |
| Machine Shop & Cryogenics | 8 |
| Plant Maintenance | 13 |
| Scientific Services | 4 |
| Administrative Services | 8 |
| | 53 |
| Total | 84 |

* USNO funds support seven full-time equivalents in this category, four positions are VLBA construction, one is associated with the summer secondary science teacher's institute, and five are in the fiscal division.

What would be the staffing levels at Green Bank were the 140-foot telescope to be mothballed? (Please list the affected positions by function).

The 140-foot telescope is the only telescope NRAO operates at Green Bank for its user community. If the 140-foot were mothballed, the rationale for NRAO's operation of the site would cease to exist. The staffing levels in Green Bank would then be entirely dependent on the U.S. Naval Observatory. It is difficult to predict the final staffing level of a stand-alone USNO operation; a rough estimate would be 10 to 15 personnel employed by USNO for as long as they retained an interest.

What were NSF's long-range plans for radio astronomy at Green Bank prior to the collapse of the 300 foot telescope?

Prior to the collapse of the 300-foot telescope, it was NRAO's plan to operate the 300-foot and the 140-foot telescopes as long as long as the scientific priority of each telescope remained competitive with other needs in radio astronomy and in astronomy as a whole. A recent review conducted for NSF to identify priorities among all radio astronomy facilities supported placed the 140-foot telescope in a group highly recommended for continued funding under all but truly disastrous funding levels and the 300-foot telescope in a group highly recommended for continued funding, but less so than other radio facilities.

For a long time NRAO has been considering the scientific requirements for a new large-aperture, fully steerable modern telescope that would replace both of the old telescopes. However, the Observatory's first priority, established with a national consensus, has been the Millimeter Array for which they planned to seek NSF construction funds. Because the new Green Bank telescope has applications in areas of research supported by NASA and the USNO, it was hoped they also would contribute to its construction.

What are NSF's plans for radio astronomy at Green Bank if the telescope is not replaced (be specific)?

If the 300-foot telescope is not replaced, NRAO will continue to operate the 140-foot with reduced staff levels. However, the long-range future of the Green Bank site cannot be in radio astronomy without a new large aperture telescope to replace the collapsed 300-foot and the 140-foot telescopes. It will not be cost effective to continue operation of the rapidly aging 140-foot telescope indefinitely. Priority must be given to new areas, such as operation of the VLBA, causing severe budgetary pressures on the remaining program.

What space applications did the 300 foot telescope have for NASA programs?

The 300-foot telescope was to make observations that would have enhanced two NASA programs. A survey of pulsars was planned to support the Gamma Ray Observatory mission. A survey of atomic hydrogen emission in the Milky Way was planned that would be valuable for interpretation of data from the Extreme Ultraviolet Explorer, ROSAT, and other soft X-ray missions.

Bi-static radar
Transmissions from Deep Space Probes
VLBI in space

What potential does a replacement telescope have for NASA programs?

In addition to the programs listed for the 300-foot telescope, a replacement telescope would contribute to programs in space very long baseline interferometry, planetary radar, and radio wavelength studies of objects observed with the Hubble Space Telescope.

How many staff will be dedicated to the gravity wave detector, on site at Green Bank (by function)?

After the initial construction phase, there will be 10 people in full-time residence dedicated to operations (site manager, computer programmer, electronics technician, mechanical/vacuum technician, plant maintenence technician, and 5 operators) plus 10 local people working under contract on development and manufacture of major new scientific components. } These latter 10 will be support people — not developers.

In addition, there will probably be 5-6 visiting scientists in residence from the user groups collaborating on mounting independent simultaneous experiments.

How many staff will be dedicated to the gravity wave detector at other sites, and type of staff?

The operating staff will be the same size, but the local manufacturing support is not anticipated to be available at more remote sites. OVRO possibility.

What will be the operating budget of the gravity wave detector at Green Bank, and other sites?

| | GREEN BANK | SECOND LIGO INSTALLATION |
|---|---|---|
| Operations (staff) | $800k | $800k |
| Power (1 MWatt) | 350 | 750 |
| Supplies and expenses | 100 | 100 |
| Laser upkeep | 250 | 250 |
| Vacuum system upkeep | 250 | 250 |
| Physical plant maintence | 250 | 250 |
| TOTALS | $2.0M/yr | $2.4M/yr |

In addition, it is anticipated that there will be $5.6M spent on several university user groups to carry out the science. This will be used for staff costs, parts and materials for receiver development, data analysis, travel and living expenses at LIGO, etc.

What applications would the gravity wave detector have for the space program?

Both ground-based and space research aim to further our fundamental knowledge of the universe--its origin and structure, as well as the mechanisms underlying the many interesting astronomical objects which occupy it. In a general way, the new information gained from the LIGO will enhance the insights to be gathered by observations in space. By combining data from all available windows (optical, infra-red, radio, x-ray, neutrino, and gravity wave) correlations between signals will be far more valuable than the seperate components in locating the positions of sources and unraveling the complexities in their behavior.

In addition, the technology development for the LIGO will help NASA in its space mission. For example, the development of stable lasers will be useful for developing high capability communications links to satellites.

An even more closely related application is that LIGO will surely be a precursor for the Laser Gravity Observatory in Space (LAGOS) project which NASA has in a study phase for a possible mission in the next century. This will search for low frequency (below 1 Hz) signals which are impossible to see on the earth due to the masking effects of seismic noise. Such signals are created by particularly interesting sources, e.g. extremely massive black holes, which would otherwise be impossible to ever observe. The LAGOS mission would consist of a laser system bouncing between satellites. It is conceptually like a LIGO scaled up by a factor of a million in size, and suspended in space.

Clearly, the technology developed for ground-based operation of the LIGO will be critical to the design of the even more complex LAGOS project.