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27 February 1991

LIGO Project
Mail Code 102-33
Attention: LIGO Site Solicitation
California Institute of Technology
Pasadena, CA 91125

To Whom It May Concern:

The National Radio Astronomy Observatory offers its Green Bank, West Virginia, site for consideration as the location of a LIGO installation. The enclosed proposal describes the offer, following the guidelines of the LIGO site solicitation. If further information is required, contact should be made with:

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National Radio Astronomy Observatory
P. O. Box 2
Green Bank, WV 24944
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Sincerely,

Paul Vanden Bout

Paul A. Vanden Bout
Director

OPERATED BY ASSOCIATED UNIVERSITIES, INC.,
UNDER CONTRACT WITH THE NATIONAL SCIENCE FOUNDATION

Site Proposal

for the

Laser Interferometer Gravitational-Wave Observatory

National Radio Astronomy Observatory
Green Bank, West Virginia

Table of Contents

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¶1. Introduction

¶1.1. LIGO Project's Study (1989) of Green Bank Site

In late 1988 Erich Bloch, then Director of the National Science Foundation, asked members of the LIGO Project to evaluate the suitability of the National Radio Astronomy Observatory's (NRAO's) site in Green Bank, West Virginia for one of the LIGO installations. The result of that investigation is enclosed, identified as Appendix A, "LIGO Construction at Green Bank Site," dated January 31, 1989. The investigation identified two possible L-configurations, each lying partly on and partly off the property occupied by NRAO. The Site Solicitation Announcement clearly states that many factors enter the site selection process. To permit that process to consider all possible alternatives, NRAO submits as its Proposal the LIGO Project's 1989 study, augmented by some additional material. Should Green Bank be selected as the best eastern site, NRAO would cooperate in hosting LIGO.

¶1.2. Viability of NRAO-Green Bank Site

The main reason for considering NRAO's Green Bank site is that it is an already developed site upon which a national user-oriented facility has been operated for more than 30 years. Accordingly, the characteristics of the site are well-determined matters of historical record; the operational experience can be used as a reliable indicator of future performance. Furthermore, the site is undergoing renewed activity, centered around the construction of the new 100-meter Green Bank Telescope (GBT), investment in which is sufficiently large that operations are likely to continue for decades. In addition to the GBT, NRAO anticipates several years of continued operation of at least the following: the 140 ft radio telescope, a Very Long Baseline Interferometry (VLBI) antenna, a twin-element interferometer, and an earth communications station for orbiting

VLBI. The resident support staff for these activities in February 1991 was 91, 26 of whom were professional people (engineers, programmers, scientists, accountants). Some growth in this staff is anticipated over the next five years. Approximately 230 visiting scientists use the facilities annually, about half of whom visit Green Bank.

Green Bank also offers remoteness from man-made disturbance or interference, a major requirement for both radio and gravitational-wave astronomy. The potential difficulty in recruiting skilled technical personnel to a remote site is minimized if a critical mass of such employees already exists. In this respect, both NRAO and LIGO would benefit from the presence of each other's staffs. The same argument can be applied to the site's attractiveness to visiting scientists: the existence of a level of scientific activity greater than either organization can support individually is a mutual benefit.

The extensive infrastructure that NRAO has put in place at Green Bank (see ¶3.11) includes many of the facilities that will be necessary for LIGO. Obviously certain efficiencies and economies can be realized if two major national facilities are co-located. It seems probable that both radio telescopes and gravity-wave detectors can operate simultaneously with neither interfering with the other. When this is not the case, radio astronomy must receive first priority.

Radio observations are particularly susceptible to electromagnetic interference. When the Observatory was established, the Federal Communications Commission also created a surrounding National Radio Quiet Zone (NRQZ) to protect against radio-frequency interference (rfi) from fixed, ground-based transmitters. A Fact Sheet describing the NRQZ is enclosed as Appendix B. Particularly relevant is the list of maximum power densities allowable at the focus of the 140 ft radio telescope at various frequencies. Since these stringent limits are imposed on off-site transmitters, the Observatory is obligated to impose these same standards upon its on-site activities. Examples of special measures employed by NRAO, which LIGO would be required to adopt as well, include:

(a) microwave screening of operations control buildings

(b) careful shielding of electronic devices against rfi leakage

(c) use of diesel vehicles only

(d) power cables underground and shielded

(e) occasional suspension of arc welding

(f) exclusion of microwave ovens

and (g) other measures judged necessary by the NRAO Site Director.

In actual practice, NRAO has not found these special rfi-reducing measures onerous.

¶1.3. Outline of Site Proposal

The Site Solicitation Announcement contained three sections requesting specific information: Site Requirements, Proposal Guidelines, and Site Selection Criteria. These will be addressed in ¶'s 2, 3, and 4, respectively, of this Site Proposal. Within each of the three sections, every item listed in the Solicitation Announcement will be addressed briefly, in order, in the text of the Proposal, where specific reference will also be made to enclosed Appendices providing extensive supporting material. In many cases, additional information may be available, which can be obtained by contacting

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¶2. Site Requirements

The principal requirements were evaluated in the LIGO Project's 1989 Study (see ¶1.1 and Appendix A). Two alignments were described, identified as GB-1 and GB-2.

¶2.1. Layout

The arms of neither alignment are precisely orthogonal: 97° for GB-1 and 87° for GB-2.

Neither arm of GB-1 meets the ≤40 ft elevation difference requirement between arm's end and vertex; GB-2 is level.

Only approximately half of each arm of either alignment lies within NRAO site boundaries. The slab supporting the vacuum pipe and its enclosure could be constructed on the portion lying within these boundaries. The question of construction beyond NRAO boundaries would have to be settled by the LIGO Project with private landowners. This does not imply that NRAO has

identified any physical or topographic reasons why the necessary construction would be impossible or even unusually difficult on adjacent lands.

¶2.2. Buildings

A vertex building could be constructed on the NRAO site. All end buildings would be off NRAO's property and would therefore be dependent on the LIGO Project's property acquisition. With respect to the midpoint buildings, the following table identifies how far from the vertex along each arm the boundary of the NRAO property lies:

GB-1	SE Arm	52%
	SW Arm	47%
GB-2	NE Arm	49%
	SE Arm	41%

Therefore, the midpoint of only one arm, the SE of GB-1, lies on NRAO property. One of GB-2's midpoints is very nearly on. Whether a building must be exactly, or only nearly, at the midpoint is for the LIGO team to judge. If the answer is exactly, then private landowners will have to be contacted; their land certainly permits building construction.

¶2.3. Crossings

The SE arm of GB-1 and both arms of GB-2 cross WV highway 28/92. Although this is the main highway in the Deer Creek Valley, typical traffic might average only about 20-30 vehicles per hour during the day, falling to one-tenth that late at night. These three arms, as well as the SW arm of GB-1, also cross sparsely traveled, rural, paved roads.

The SW arm of GB-1 crosses Deer Creek, a feeder stream to the Greenbrier River. Near the Creek would be wetlands, some of which occasionally flood, but the Creek is unlikely to rise to the height at which the vacuum pipe would cross it. The other three arms cross more minor creeks. Hazards on the land--earthquakes, floods, inadequate drainage--do not present insuperable barriers.

¶2.4. Road Access

Appendix C.1, "Site Map," shows the location of existing paved roads on the Observatory. These provide excellent access to most areas of the site. Dirt roads provide access to some other

regions as well. While the Green Bank Telescope is under construction during 1991-1994, the roads running from the GBT Site to the Interferometer Range and to the GB Elementary & Middle School may be dedicated for GBT construction exclusively.

¶2.5. Service Road

On the NRAO portion of the two configurations, a service road could parallel the vacuum pipes. Assuming the land beyond the Observatory site boundaries can be acquired, there appears no reason the service roads could not be constructed there also.

¶2.6. Electrical Power

The main NRAO transformers, marked on the Site Map of Appendix C.1, are less than half a mile from the vertices of the two configurations. Site capacity is 2.5 MW, of which 1 MW is used now and a second will be when the GBT is operating. LIGO would therefore require another transformer. The trunk power line to the site would, however, be adequate to carry an additional MW for LIGO.

¶2.7. Water and Sewer

A well, water storage tank, and distribution system, and a waste-water treatment plant, serve the area on the site from the entrance at the Guard House to the Works Area Building (see Appendix C.1). Elsewhere on the NRAO property, service is by local well and septic tank. These may be the recommended options which LIGO would have to install. Sewage, in particular, would otherwise have to be pumped uphill from the vertex building to the existing waste treatment plant; water could be delivered to a vertex room via pipe from the storage tank, but probably at a cost comparable to, or greater than, that of drilling a new well.

¶2.8. Geotechnical Features

Extensive soil studies, conducted in connection with GBT construction, prove that foundation settlement will not be a problem (see ¶3.3). Subsurface conditions will easily support the $\approx$3,100 lbs/ft^2 the GBT is designed to exert (*vs.* 2,000 lbs/ft^2 specified for LIGO).

¶2.9. Remoteness and Convenience

LIGO's requirements to avoid man-made noise are identical to those which led NRAO to select its Green Bank, WV site. Nothing in the more than 30 years of experience there has shown it to be less than superb in this respect.

The Site Map (Appendix C.1) shows the proximity of the Green Bank Elementary and Middle Schools. The National Radio Astronomy Observatory map of Appendix C.2 shows the High School, 13 miles from the Observatory and served by school bus transportation.

Housing, shopping, and services are available in and between the communities on Appendix C.2's map from Bartow to Frost and from Minnehaha Springs to Marlinton, all less than an hour's drive from NRAO.

NRAO partially subsidizes a medical clinic, shown on C.1's Site Map. NRAO employees also operate volunteer ambulance and fire services. Volunteer emergency services are also provided by surrounding communities.

The Observatory has an airstrip available for official business only. It can be used only under daytime visual flight rules; no instrument or night takeoffs or landings are possible. Nor is there any tower control. It may be closed following construction of the Green Bank Telescope. Appendix C.3, "Closer Than You Think," provides information about access to Snowshoe Mountain Resort. Snowshoe is a thirty minute drive from Green Bank.

Some facts about Pocahontas County, West Virginia are summarized in Appendix C.4.

¶2.10. Site Preparation Costs

The LIGO Project 1989 Study, Appendix A, estimated costs of $12.4M (GB-1) and $23.2M (GB-2) for earthwork, accommodation of special features, de- and re-forestation, drainage, and concrete enclosures. The concrete enclosures are not properly part of the site preparation costs requested. Corrected estimates for site preparation only of GB-1 and GB-2 are therefore $8.3M and $18.7M, respectively, not including the costs of an electrical transformer, wells, septic tanks, or land acquisition. This proposal has added no corrections for the effects of inflation since January 31, 1989.

¶3. Proposal Guidelines

This section describes the source of the supporting material requested.

¶3.1. Maps of LIGO Site

Maps on different scales have been presented as Appendices C.1, C.2, and C.3, as well as on the NRQZ Fact Sheet, Appendix B.

¶3.2. Topographic Map

A topographic map and elevation profiles were presented in the LIGO Project Study, Appendix A. NRAO re-superimposed the configurations GB-1 and GB-2 on a topographic map, and encloses the result as Appendix D. The elevation profiles have not been repeated.

¶3.3. Geotechnical Data

Two reports provide very extensive data:

Appendix E.1. "Report on Geological Foundation Conditions as to Suitability for a Radio Astronomy Station at Green Bank, Pocahontas County, West Virginia," by Price, Davis, and Hunter (1956).

Appendix E.2. "Subsurface Investigation and Geotechnical Engineering Evaluation--New 10 Meter Diameter Radio Telescope, National Radio Astronomy Observatory, Green Bank, West Virginia," by Triad Engineering Consultants, Inc. (1990).

¶3.4. Climate and Environmental Risks

Appendix F.1 summarizes "Selected Climatic Data for Green Bank, WV."

Additional information is provided in Appendix F.2, "The Climate of West Virginia"; unusual storms are covered therein under the heading "Winds and Storms." This report was written in 1960; NRAO's own experience since then verifies it continues to be an accurate qualitative description.

Appendix F.3 provides "A Summary of Wind Statistics for Green Bank."

¶3.5. Access for Utilities and Transportation

The fact that several major radio telescopes and buildings have been built and operated in Green Bank attests to its accessibility for the utilities and transportation needed to construct and operate a major scientific facility. Appendix G, "GBT Site--Green Bank, WV: Immediate Area

and Site Information," summarizes information about accessibility.

¶3.6. Present Land Ownership

The topographic map of Appendix D marks the boundaries of the National Radio Astronomy Observatory. Land within those boundaries is owned by the federal government. NRAO would cooperate with an NSF request to make part of the bounded land available for LIGO. The LIGO Project Study, Appendix A, identified the total number of private landowners upon whose property the arms of the L would pass: for configuration GB-1 the total was 14; for GB-2 it was 7.

¶3.7. Purchased Land

Acquisition by purchase or lease of the land held by private land owners would be the responsibility of the LIGO Project. Transfer of the land to the Government or to Caltech would also be the responsibility of the LIGO Project.

¶3.8. Future Development

LIGO and NRAO would share a common interest in seeing that future urban or commercial development did not create unwanted "noise". Noise could be defined as radio-frequency interference, heavy industrial activity, heavy vehicular traffic, earth moving on such a scale that it created vibration problems, or the like. No such developments are currently planned or have happened in the previous thirty years of NRAO's presence in the Green Bank area. The populations of Pocahontas County and of West Virginia declined during the 1980s, precisely because major economic development projects were lacking. NRAO enjoys good relationships with local, state, and national government officials, so its concerns are seriously considered for those projects in which governmental agencies are involved.

A West Virginia statute, similar to the FCC regulations establishing the National Radio Quiet Zone, protects the Observatory out to a radius of ten miles against installation of electrical equipment that might interfere with radio astronomy observations. Since most heavy industries would require use of such equipment, the statute could be used as assurance of a buffer zone around the Observatory. In practice, it has never been necessary to resort to the legal protection of

this statute, appended as Appendix H, "House Bill No. 2."

¶3.9. Environmental and Procedural Issues

NRAO has never had a Green Bank project forbidden or even excessively delayed by environmental or procedural issues. LIGO construction would, of course, require an Environmental Impact Statement. Many of the factors required in such a Statement have already been assembled for an Environmental Assessment filed and approved in 1990 for the construction of the Green Bank Telescope.

¶3.10. Cooperation on Geotechnical Investigations

Possibly the geotechnical data necessary for LIGO evaluations might already exist (see Appendices E.1 and E.2). If more investigations are needed, NRAO would cooperate as long as these investigations did not interfere with the normal operations of a radio observatory. NRAO anticipates they would not.

Past NRAO cooperation during the period of the LIGO Project's 1989 Study in Green Bank can serve as a model for how future relations would be conducted.

¶3.11. Additional Support from NRAO

The National Radio Astronomy Observatory provides a developed site having an active scientific environment, specialized technical services and facilities, a user orientation, and an academic research atmosphere. Thus LIGO staff and users should find it an attractive place to work, one permitting a high level of research productivity. An extensive infrastructure already exists at the Green Bank facility. Use of some portions of it by LIGO could be negotiated with NRAO. Since the infrastructure and the people who maintain and operate it are already oversubscribed, however, LIGO would be expected to pay a reasonable share of the annual operating costs, as well as all costs associated with new demands. Nevertheless, the LIGO Project should realize significant savings by avoiding duplication of some capital costs. Money saved by avoiding duplication could be used instead to enlarge the pool of resources available to all. Then both projects would have more resources but at less than the price either would have to pay on its own. The National Radio Astronomy Observatory's primary mission will continue to be support

of radio astronomical research. When pooled resources are requested by both NRAO and LIGO, NRAO's needs would receive priority attention.

Without making specific commitments for their shared use, but with the expectation that reasonable and mutually beneficial agreements are possible, a partial list of existing infrastructure is presented:

Electronics Laboratory
Cryogenics Laboratory
Computer Local Area Network with an Internet node
Scientific and Technical Library
Machine Shop
Office Space
Vehicle Maintenance Garage
Warehouse
Heavy Equipment (crane, bulldozer, motor grader, snow plow, etc.)
Photographic Darkroom
Weather Station
Emergency Services
Residence Hall for visiting scientists, containing 16 rooms and 4 apartments
Cafeteria
Recreation Facilities

¶3.12. Duration of the NRAO Proposal

There is no time limit. The offer stands.

¶4. Site Selection Criteria

The Site Solicitation Announcement concludes with a list of selection criteria. Nearly all of these have been addressed in the foregoing text or appendices to it. In the following, the Proposal will cross-reference where each criterion has been addressed and will comment on those criteria not addressed to this point.

¶4.1. Science Impact

¶4.1.1. Local Parameters. Site Topography has been addressed in ¶'s 2.1, 2.2, and 2.3, and in Appendices A and D. Ground vibration spectra are discussed in ¶'s 2.8, 3.3, and 3.10, as well as in Appendices E.1 and E.2.

¶4.1.2. Global Parameters. These can only be assessed in comparisons with other site proposals.

¶4.2. Construction Cost Impact

¶4.2.1. Topography. The required earth movement was identified in Appendix A, as was its cost. See also ¶2.10.

¶4.2.2. Soil and Subsurface Conditions
and
¶4.2.3. Hydrology and Drainage. See again ¶'s 2.8, 3.3, and 3.10, as well as Appendices E.1 and E.2.

¶4.2.4. Climate. See ¶3.4 and Appendices F.1, F.2, and F.3.

¶4.2.5. Environmental Restrictions. See ¶3.9.

¶4.2.6. Accessibility. Relevant information is in ¶'s 2.4, 2.9, and 3.5, and in Appendices C.1, C.2, C.3, and G.

¶4.2.7. Site Utilities Installation. Refer to ¶'s 1.2, 2.6, 2.7 and to Appendix C.1.

¶4.2.8. Proximity of Soil Waste and Borrow Areas. The County's landfill was identified on the map of Appendix C.2. It is less than 20 miles from the Observatory. Limited borrow areas are available on NRAO. Others must certainly lie within a 50-mile radius.

¶4.2.9. Local Labor Costs. The U.S. Department of Labor's "General Wage Decision No. WV90-3" presents so-called Davis-Bacon wages for West Virginia. It is enclosed as Appendix I.1. General economic conditions, including employment statistics, are discussed in Appendix I.2, "West Virginia Economic Summary, December 1990."

¶4.3. Site Availability and Acquisition Costs

LIGO's vertex building, approximately half of each arm of the L, and some or all of the midpoint buildings could be placed on land, already owned by the federal government, within the boundaries of the National Radio Astronomy Observatory (see ¶'s 1.1, 2.1, 2.2, 2.5, 3.6, and 3.7, and Appendices A and D). The land needed for the remaining portions of each arm, for the end buildings, and for those midpoint buildings which do not lie on the NRAO site would have to be purchased from private landowners by the LIGO Project. Availability and cost are prerogatives of those landowners.

¶4.4. Existing Support Infrastructure

¶4.4.1. Accommodations for Resident Staff. Refer to ¶2.9 and to Appendices C.1, C.2, C.3, and C.4.

¶4.4.2. Accommodations and Access for Visiting Staff. Refer to ¶3.11. This should be a particular strength of this proposal.

¶4.4.3. Local Technical Support. Available support off-site is adequate to permit operation of a radio observatory, perhaps the same level of activity as required by a gravitational-wave observatory. NRAO staff represent a cross-section of crafts and skills akin to what LIGO would require; the optimum use of that staff, presumably augmented, for both NRAO and LIGO would have to be investigated and cost-sharing negotiated.

¶4.5. Operations Cost Impact

¶4.5.1. Cost of Power. Appendix J.1, "General Service Rate, Schedule 'D'," from Monongahela Power Company presents the rate schedule in effect at the beginning of 1991. Appendix J.2, "Annual Electric Power Cost Estimate," presents a sample calculation of an annual energy bill for continuous operation at a 1 MW rate of power consumption.

¶4.5.2. Cost of Local Labor. Refer to ¶4.2.9 and to Appendices I.1 and I.2. Davis-Bacon wages are required only for construction projects. When LIGO begins operating, it will employ people with the same skills as NRAO employees. Both the intimate working environment and the rural community structure mean each set of employees is likely to have an accurate knowledge of the wages and benefits of the other. To minimize employee dissatisfaction and management difficulties, both sets of resident staff, with the exception of scientists, should be employed by the same institution, namely NRAO/AUI. The enclosed "Salary and Wage Manual," Appendix K would apply in 1991.

¶4.5.3. Heating and Cooling Requirements. Average annual heating degree days is 6500. See ¶3.4 and Appendices F.1, F.2, and F.3 for additional weather data.

¶4.5.4. Maintenance Requirements. Co-location with another national facility holds at least the possibility that maintenance costs could be minimized (see ¶'s 1.2 and 3.11).

¶4.5.5. Travel Time and Costs for Visiting Staff. Green Bank is an established visitor facility. Its accessibility is comparable to that of most astronomical observatories. The information in ¶2.9 and in Appendix C.3 addresses the travel issue.

¶4.6. Risk Factors

¶4.6.1. Environmental Risks. The region is quiescent to earthquakes. Landslides do not occur along the valley floor where LIGO would be located. Wind statistics are presented in Appendix F.3. West Virginia experienced a major flood, of the once-per-100-year variety, in 1985. The Observatory suffered no damage. On the contrary, it served as an emergency refuge for stranded travelers, a staging area for law enforcement rescue services, and a communications link to the outside world. Observing statistics for NRAO's 140 ft radio telescope, summarized for the period 1980-1989 in Appendix L, "140-Foot Radio Telescope Summary," show that significantly less than ten percent of all time is lost to the combination of equipment failure, weather, and

interference; weather is typically a minor contributor to the combination.

¶4.6.2. Potential Future Man-made Noise from Development. Refer to ¶3.8.

¶4.7. Security of Facility and Access for Visiting Staff

West Virginia enjoys the lowest per capita crime rate of the fifty states. During more than thirty years operating in Green Bank, NRAO has suffered no serious theft or vandalism; it therefore no longer feels the need for night watchpersons. No classified research is conducted. Visiting scientists have open access to all facilities. They may enter the Residence Hall, the Jansky Laboratory (the main office and electronics building), and the 140 ft telescope at any hour on any day.

¶4.8. Local Contributions--Financial or Other

The National Radio Astronomy Observatory is operated by Associated Universities, Inc. (AUI), under a Cooperative Agreement with the National Science Foundation. AUI is a not-for-profit research management organization and is not in a position to offer any financial inducements. The in-kind contributions that may be possible have been discussed in ¶'s 1.2 and 3.11.

List of Appendices