SUPPLEMENTAL PROPOSAL

to NSF GRANTS
PHY-8504136
PHY-8504836

in support of a

CALTECH/MIT PROJECT FOR A LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY

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PROJECT SUMMARY

This proposal requests support for a three-month extension of an ongoing research and development program towards the establishment of a Laser Interferometer Gravitational Wave Observatory (LIGO). The proposed effort is a joint undertaking of the California Institute of Technology and the Massachusetts Institute of Technology. We propose to continue the development of gravity wave prototype receivers and their support facilities, to perform analytical work in support of the activities, and to largely complete the conceptual design of a full scale LIGO.

I. INTRODUCTION

This proposal requests supplemental funding and an extension of the grant period for a joint Caltech/MIT program of research and development towards the establishment of a Laser Interferometer Gravitational Wave Observatory (LIGO).

The work so far has been supported under separate NSF grants to two science groups at Caltech and MIT:

Award: PHY-8504136
Amount of Award: $3,986,319
Award Period: July 1, 1985–February 29, 1988
Title of Project: "Investigations in Experimental Gravity and Gravitational Radiation"
Principal Investigator: Ronald W. P. Drever, Caltech

Award: PHY–8504836
Amount of Award: $3,389,600
Award Period: June 1, 1985–February 29, 1988
Title of Project: "Interferometric Broadband Gravitational Antenna"
Principal Investigator: Rainer Weiss, MIT

Grant funds were applied to research and development activities in gravity-wave receivers, the principal focus of the program, and to preparatory work towards the establishment of the LIGO facilities, (large scale vacuum systems and their enclosures, support structures, and observatory sites). This work has been described in detail in a recent proposal to NSF: Caltech/MIT Project for a Laser Interferometer Gravitational Observatory (submittal date: December 1987, NSF Proposal ID No. PHY–8803557, proposed start of grant period: 1 June 1988).

The funds requested under this proposal are intended to bridge the gap between the existing Caltech and MIT grants and the future support requested in the December 1987 proposal.

In accord with the recent reorganization of the LIGO project, the Principal Investigator and Project Director for the grant extension will be R. Vogt, with R. Drever and R. Weiss serving as Co-investigators. Support of the MIT Science Group activities will be provided under a subcontract from Caltech to MIT under the proposed grant extension.

II. PROPOSED WORK

The planned research and development effort during the proposed grant extension period is a continuation of the work performed under the prior grant, and will lead to the activities slated for the post-June 1988 grant period discussed in the December 1987 proposal. The proposed work will be a joint effort of the Caltech and MIT science groups and the LIGO engineering team. The work falls broadly into the following areas:

A. Enhancements of the capabilities and the strain sensitivity of the 40-meter Fabry-Perot interferometer prototype, located on the Caltech campus.
B. Design, construction, and operation of a new 5-meter Fabry-Perot interferometer prototype, located on the MIT campus.
C. Development and testing of advanced LIGO technology with particular emphasis on components important to operational, full scale LIGO receivers.
D. Analytic work on scaling properties of LIGO receiver designs.
E. Data analysis of prototype interferometer trial observing runs.
F. Planning for and conceptual design of LIGO facilities (sites, buildings, vacuum system, etc.).

Specific efforts in these areas are:

1) 40-meter Fabry-Perot prototype activities

(a) Narrow-band optical filtering of input laser light.

Investigations of limiting noise sources in the 40-meter interferometer system suggest that high-frequency laser noise, at frequencies outside the gravity wave range of frequencies, can introduce noise by non-linear processes in the photodiode/electronic system. An in-line cavity designed originally for geometric filtering of the beam, suppresses frequency components of the laser light more than 250 KHz from the mean frequency, improving sensitivity and providing support for the hypothesis. We plan to narrow the optical bandwidth of the mode cleaning cavity to 80 KHz in the next step by use of a new design with improved seismic isolation and high mechanical quality factor, giving a lower-noise frequency reference. The new cavity will also transmit higher laser power than the original one. Planned experiments include first tests with the filter cavity in a separate vacuum tank coupled by optical fiber to the main interferometer, then elimination of the coupling fiber and closer integration of the filter cavity to the main interferometer, where it will form part of the beam directing system.

(b) Improvements of the laser light source system.

To reduce photon shot noise limitations on sensitivity concurrently with reduction of other noise sources, an improved laser stabilizing system is being developed. The current system uses an electro-optic phase modulator within the laser cavity as a fast control element. This internal Pockels cell restricts the available laser power, for it suffers radiation damage at high power. This limitation will be overcome in a new stabilizing system in which the internal Pockels cell is replaced by a piezo-driven laser cavity mirror designed for the highest practical frequency response (first resonance about 200 KHz), supplemented by an external Pockels cell used as a secondary optical phase correcting element of limited range but fast response. This new system will initially use the improved mode cleaner/filter cavity as a prime frequency reference, with some high-frequency correction from the main interferometer; subsequently a second stage of phase stabilization is planned to improve performance further.

(c) Mechanical improvements.

A suspected source of low-frequency noise in the present interferometer is mechanical noise in beamsplitters and auxiliary optics outside the main Fabry- Perot cavities. We plan to rebuild this system by replacing the mechanically complex structure of components on a common support with separately suspended and servo-controlled optical components, designed for operation in beam-recombining modes as well as in the current individual-cavity arrangement. This development will follow the optical filtering and laser improvements, and may not be completed during the proposed grant period.

To facilitate research on the more complex optical systems now planned, work is proceeding to replace by a six-foot diameter chamber the 18-inch diameter tank and its extensions. Construction and development of the improved and enlarged test-mass support and isolation system associated with the new chamber will continue during the grant period.

(d) Further development and refinement of automatic alignment systems.

The first practical application of the prototype automatic cavity wavefront phase matching system will be to keep the alignment of the input laser beam optimized to the optical axis of the filter cavity. This will provide improved alignment and throughput, as well as giving active isolation of the interferometer from mechanical drifts and vibration of the laser without the power limitations and losses of the fiber coupler currently used. A computer-controlled backup system, which maintains alignment if the cavity drops out of resonance temporarily, will be incorporated.

(e) Development of an active system for improving isolation from low frequency seismic disturbances.

An auxiliary interferometer monitors relative motions of the test mass suspension points at the ends of each interferometer arm, providing feedback signals to lock the points together. Operation of this system on one arm is currently being tested, and further development and extension to both arms is planned. This should improve rejection of large disturbances, reducing dynamic range problems in the main servo systems, as well as extending interferometer operation to lower frequencies.

2) 5-meter Fabry-Perot prototype activities

(a) Completion of the 5-meter facility.

The internal structure consisting of the support posts, bellows, isolators, and vacuum compatible optical tables should be in place by February 1988. We have experienced delays in obtaining electrical and optical feedthroughs. These will most likely be installed in March. In March we will be installing optical ports in the main flanges as well as safety support posts and individual chain hoists on the tanks. A clean air backfill system will be installed in April. The facility should be complete by the beginning of April.

(b) Preparatory work in developing the optics for a recombined beam Fabry-Perot prototype.

We will assemble the modulation optics and reference cavity and order the mirrors for the 5-meter prototype interferometer. The specific design of the recombined Fabry-Perot system is not firm at present and will be developed in coordination with work being carried out on the 40-meter system; the equipment required is not specific to a particular recombination scheme. The initial operation of the prototype as a complete system with suspended masses is anticipated in the middle of 1989.

(c) Design of a common instrumentation system for both the 40- and 5-meter prototype facilities.

The LIGO project will standardize the computer and computer/instrumentation interface systems for prototype monitoring and data collection. The design of the system is being driven by the 5-meter construction activities and will evolve during this period leading to equipment purchases during the subsequent three-year grant.

(d) Development of suspension systems.

A test version of the guard mass/mirror suspension system using magnetic and electrostatic controllers and quadrant diode/LED position sensors will be placed in the suspension test tank during this period. The tests are being made to determine the isolation factor and the stability of the normal mode damping. The suspension, once tested, will be replicated for the nine independently suspended masses in the 5-meter system. During this period we will begin placing orders for the long-lead items in the suspension, in particular vacuum compatible motors and translation stages.

Work will continue on measuring the isolation and damping of the magnetic suspension system as an initial stage of vibration isolation for the guard mass/mirror suspensions. The system is now floating reliably. The decision on whether to use the magnetic suspension or passive damped springs will be made during this period.

Work will continue on a large dynamic range, high sensitivity position transducer based on fiber-optic interferometry. A solid state distributed feedback laser has been ordered under prior grant funds. This is expected to arrive in February or March. The laser should be less noisy than the present system and more importantly, since it oscillates in a single mode, should permit a larger dynamic range for the transducer. We expect that the decision on whether or not to standardize and replicate this transducer will be made during the grant period.

3) Development of light sources for interferometric detectors

Work will continue on the development of an all solid-state Nd:YAG oscillator amplifier combination based on a monolithic ring laser coupled to a small end pumped slab amplifier. The rapid development of laser diode pump sources has made it economically feasible to build a 1 to 10 watt system now. The gain of the Nd:YAG grows by a factor of 5 if operated at liquid nitrogen temperature and the expectation is that diode pumps, provided they are sufficiently doped so as not to suffer carrier freezeout, will be 4 to 5 times more efficient at low temperature. (Sample diodes are being tested currently.)

4) Analytic work to establish the scaling properties of receiver designs for the LIGO

An analytic program has been started to determine:

a. The effect of scattering on the performance of a long baseline Fabry-Perot.
b. The alignment sensitivity and wavefront distortion due to mirror transmission and heating in a long baseline Fabry-Perot.
c. The servo system design and stability in a long baseline Fabry-Perot.

The calculations and modelling were begun in the prior grant period and will continue through this period.

5) Data analysis

The first three-fold coincidence observing runs with interferometric receivers located at Caltech, Glasgow, and MIT were successfully done in February and March 1987, shortly after the appearance of Supernova 1987A. Although one expects any possible signals to fall below detection thresholds, the data will be analyzed as part of Ph.D. dissertations, and experience will be gained in the development of algorithms and data analysis techniques. The experience will influence the design of the interferometer facilities.

6) Planning and design of LIGO facilities

The engineering team will be further strengthened during the proposed grant period by the judicious addition of key staff. A focus of the engineering activities, with active support from the science groups, will be the completion of the conceptual design of the full-scale LIGO facilities, including work with a vacuum prototype in support of the design of the vacuum system. Site selection, surveys, and geotechnical work will be continued, as required for the Preliminary Engineering Design proposed for the follow-on grant. A favorable computing environment in support of both science and engineering activities will be installed. Preparations for procurement of the Preliminary Engineering Design will be made.