LIGO-T970134-00-I

# Contributions toward LIGO Data Analysis

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May 20, 1997

## 1 Introduction

We propose that Finn's research group spend a one year — beginning 1 September 1997 and ending 31 August 1998 — with the LIGO project, based primarily at Caltech. During that year Finn's research group will focus its efforts primarily on problems associated with the data stream (management, archiving, transportation, and analysis) that are important for the operations and analysis of the initial interferometers ("LIGO I"). The particular problems addressed will be those that best capitalize on the physical proximity of Finn's research group to the LIGO science team at Caltech.

## 2 Personnel

Four personnel will participate in this effort. All will hold appointments at Northwestern University; however, all will be based at Caltech during the one year period beginning 1 September 1997. The personnel and their Northwestern University appointments are

1. Lee Samuel Finn (P.I.), Associate Professor of Physics and Astronomy, Northwestern University;
2. Soumya Mohanty, Research Associate, Department of Physics and Astronomy, Northwestern University;

3. Soma Mukherjee, Visiting Scholar, Department of Physics and Astronomy, Northwestern University;

4. Joseph Romano, Research Associate, Department of Physics and Astronomy, Northwestern University.

While at Caltech, Finn will hold a Caltech appointment as a Visiting Associate; Mohanty, Mukherjee and Romano will hold appointments as Visitors.

# 3 Research

Preliminary discussions with B. Barish, LIGO Director and P.I., have identified several areas of common interest where the skills of Finn's research group can contribute to the LIGO project goals. These are described below. Each member of Finn's research group will work primarily on one of these projects in collaboration with appropriate LIGO personnel; Finn will supervise the progress of members of his research group while working also on projects of his own in collaboration with LIGO project personnel.

**Monte Carlo simulations for data analysis.** Characterizing the performance of data analysis algorithms requires testing on data whose content is known. Mohanty will work develop a data simulator for use in testing analysis software. The simulator will be integrated into the existing LIGO end-to-end simulation model. The simulated data stream will include both signal and noise components. On the noise side, the data stream will include Gaussian, non-Gaussian and non-stationary noise sources. The character of the non-Gaussian and non-stationary noise sources will be drawn from investigations of the data records from existing interferometers. On the signal side, injection of both deterministic and stochastic signals drawn from anticipated astrophysical sources. **Mohanty** will take the lead in working with LIGO project personnel in this effort.

**Characterization of non-Gaussian and non-stationary noise sources.** Gaussian noise arising from fundamental processes (*e.g.,* LASER shot noise or thermal noise) can generally be anticipated and characterized *a priori;*

consequently, the analysis of data generally begins by assuming that the signal is additively superposed with Gaussian-stationary noise. Non-Gaussian and non-stationary noise sources generally are the result of processes that are not well understood and are difficult to anticipate or characterize; nevertheless, data analysis must recognize and accommodate the presence of these noise sources. Working with data from existing gravitational-wave detectors (both interferometric and acoustic) we will work to develop tools that can be used for identifying and characterizing non-Gaussian and non-stationary noise in the LIGO data stream.

Efforts in this direction are part of an ongoing effort within the LIGO project. We are not proposing to start a new or independent effort in this area; rather, we are proposing to integrate our own expertise into the existing effort within the LIGO project. **Mukherjee** has been studying techniques for identifying and characterizing non-Gaussian and non-Stationary noise sources using the 100-hour Glasgow-Munich data run and will take the lead on this project.

**Stochastic signal detection.** Allen has implemented a prototype data analysis for stochastic signals based on the work of [1, 2, 3]. This analysis derives from the perspective of Frequentist data analysis, which focuses on the characterization of decision rules based on *ad hoc* measures of the data. Bayesian data analysis offers a different perspective on data analysis, which focuses on an assessment of the probability of signal presence in a particular data stream. I have described the Bayesian data analysis for stochastic signal data analysis and propose to develop a prototype analogous to Allen's with the goal of a comparative analysis of the performance of these two prototypes on simulated LIGO data. **Romano**, who worked with Allen on the development of the Frequentist stochastic signal data analysis prototype, will be primarily responsible for developing the Bayesian analysis prototype.

**Data analysis for generic impulsive burst events.** Burst sources of gravitational radiation with detectable intensity generally result in the destruction of the source. On very general grounds we expect the waveform of the final burst of radiation emerging from such a source to have the character of an exponentially damped sinusoid (this is certainly true of anticipated burst sources like binary coalescence, black hole formation, and gravitational core collapse). **Finn** will work to implement an analysis prototype for the detection and characterization of these generic burst events.

**Data analysis for multi-detector receivers.** The output of the several LIGO interferometers can be analyzed individually, as distinct gravitational-wave receivers acting in isolation, or coherently, as part of a larger, logical gravitational-wave receiver. Analysis of the data stream from a multi-detector receiver, as opposed to separate analyses of an equal number of isolated single-detector receivers, requires more sophisticated data handling and analysis techniques; however, the marginal gain in instrument sensitivity and extractable science is enormous. **Finn** will develop his analysis prototype for generic burst events into an analysis prototype for generic burst events in a multiple-detector receiver.

**Data stream management and analysis.** There are a number of decisions regarding the management of the LIGO data stream yet to be made; for example,

- What pre-processing of the data stream will take place on-site, at Hanford and Livingston?
- What will be archived locally (*i.e.,* on site), and for how long?
- What kinds of data analysis will be carried out on-line at the sites?
- What fraction of the data stream will be forwarded off-site for archiving and analysis? Will data forwarded off-site be streamed or batched?
- If batched, what will be the delivery frequency and format: *e.g.,* hourly by high speed data link, daily by tape, *etc?*

The answers to these questions are affected by the physics associated with the anticipated sources (*e.g.,* the gravitational-wave signals associated with stellar core collapse will arrive several hours before any associated supernova becomes visible; consequently, timely identification of core collapse gravitational-waves is critical) and have implications for the for the personnel and computing power needed at each site. **Finn** will work with the LIGO project personnel currently investigating these issues to help define the criteria by which these decisions are to be made and, where possible, help make the decisions.

# 4 Resources

**Salary.** The LIGO project will, through a purchase sub-contract to Northwestern, pay for 1/2 of Finn's 9 month academic year salary for the period beginning 1 September 1997. In the budget for this subcontract (attached) the salary for this period is estimated; the actual salary is expected to be determined by the end of June 1997. The LIGO project will not be responsible for salary expenses of other members Finn's research group.

**Relocation expenses.** The LIGO project will reimburse up to $18,400 of Finn's travel and living expenses (to include airline tickets, rent for an apartment in Pasadena, and any miscellaneous living expenses that have to do with relocation) associated with his one year leave with the LIGO project. These expenses will be reimbursed directly by the LIGO project and separately from the purchase order sub-contract to Northwestern described above. The LIGO project will not be responsible for relocation or living expenses of the research associates of Finn's research group.

**Office space, computers, phone and other office supplies.** The LIGO project will provide office space, computer workstations, desks, phone and other reasonable office supplies for Finn and the members of his research group.

# 5 Budget

See attachment. Benefits are charged as 19.25% of salary and are counted as a direct cost; since all the work associated with this proposal will be carried out off-campus, overhead is charged as 26% of direct costs.

# References

[1] Peter F. Michelson. On detecting stochastic background gravitational radiation with terrestrial detectors. *Mon. Not. R. Astron. Soc.*, 227:933–941, 1987.

[2] Nelson Christensen. Measuring the stochastic gravitational-radiation background with laser-interferometric antennas. *Phys. Rev. D*, 46(12):5250–5266, 15 December 1992.

[3] Eanna E. Flanagan. Sensitivity of the Laser Interferometer Gravitational Wave Observatory to a stochastic background, and its dependence on the detector orientations. *Phys. Rev. D*, 48(6):2389–2407, 15 September 1993.