

**Analytic and Interferometric Techniques
for the Laser Interferometer Space Antenna**

by

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The final copy of this thesis has been examined by the signatories, and we find that both the content and the form meet acceptable presentation standards of scholarly work in the above mentioned discipline.

Pollack, Scott E (Ph.D., Physics)

Analytic and Interferometric Techniques

for the Laser Interferometer Space Antenna

Thesis directed by Professor Peter L. Bender and Dr. Robin T. Stebbins

The Laser Interferometer Space Antenna (LISA) is being designed to detect and study in detail gravitational waves from sources throughout the Universe such as massive black holes. The conceptual formulation of the LISA space-borne gravitational wave detector is now well developed. The interferometric measurements between the spacecraft remain one of the most important technological and scientific design areas for the mission.

Our work has concentrated on developing the interferometric technologies to create a LISA-like optical signal and to measure the phase of that signal using commercially available instruments. One of the most important goals of this research is to demonstrate the LISA phase timing and phase reconstruction for a LISA-like fringe signal, in the case of a high fringe rate and a low signal level. To this end we have constructed a table-top interferometer which produces LISA-like fringe signals.

Over the past few years questions have been raised concerning the use of laser communications links between spacecraft to transmit phase information crucial to the reduction of laser frequency noise in the LISA science measurement. The concern is that applying medium frequency phase modulations to the laser carrier could compromise the phase stability of the LISA fringe signal. We have modified our table-top interferometer by applying a phase modulation to the laser beam in order to evaluate the effects of such modulations on the LISA science fringe signal. We have demonstrated that the phase resolution of the science signal is not degraded by the presence of medium frequency phase modulations.

Each spacecraft in LISA houses a proof mass which follows a geodesic through space. Disturbances that change the proof mass position, momentum, and acceleration will appear in the LISA data stream as additive quadratic functions. These *data disturbances* inhibit signal extraction and must be removed. Much of our analytical work has been focused on discussing the identification and fitting of monochromatic signals in the data set in the presence of data disturbances. We also present a preliminary analysis of the extent of science result limitations with respect to the frequency of data disturbances.

Dedication

To my mother,
Kimberly Ann Pollack,

for her endless support and encouragement,
she carried me throughout all of this.

And also to
Karinita Whittlesey,

a companion like no other.

Acknowledgments

I would like to individually thank the many people who have contributed to and assisted me on my project. This is no small task, and I will most likely miss several people who deserve mention. I apologize now for any omission, and deeply thank those omitted for their contributions.

Foremost I would like to thank my advisors Tuck Stebbins and Pete Bender. Tuck accepted me as a graduate research assistant without ever meeting me. The only work of mention he had to judge me by was my undergraduate honors work which was focused on detector modeling for a high-energy solar imaging experiment, a vastly different type of research than the kind I would do at JILA.

During my first summer and the following few months I was aided by a postdoc — Oliver Jennrich. Oliver had taken the design of Joe Giaime and implemented a first generation table-top interferometer for the work I have now completed. During this past year I had the privilege to meet with Joe, and I would like to thank him for the hard work he did in the basic designing of this interferometer. Although the time I spent with Oliver was short, I would like to thank him for the knowledge I was able to imbibe from him.

A year after I began work at JILA, Tuck received an offer to become the LISA Project Scientist located at NASA's Goddard Space Flight Center in Maryland. Although the progress I had made in my first year was small (only a few characterizations of electrical components, and some simple interferometric analyses), he was confident that I would be able to continue my work albeit his vacancy.

I would like to thank Tuck for his belief in my abilities and his continued guidance over the past several years.

As Tuck departed I came under the tutelage of Peter Bender. The wealth of information that I have received from Pete most likely never will be exceeded. The many projects Pete has had me work on have allowed me to follow my goals and aspirations. I would like to thank him for supporting me over the past four years and allowing me to venture into fields of research that interested me most.

I would like to thank Jan Hall for our numerous conversations and his insights into the many problems I have encountered. I would also like to thank Jan for lending a laser which was used early in this experiment.

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The electronics staff at JILA always have been courteous and supportive. I would like to deeply thank Terry Brown for the many conversations, helpful tips, letting me use his workbench for a summer, and clever design strategies. I would also like to thank Carl Sauer for his help on much of the later work on my project. Through Carl and Terry my understanding of electronics has risen from simple understanding of semi-conductors to the ability to design and construct complex circuitry. My appreciation for their help over the years is unbounded.

The computing staff at JILA, in particular Peter Ruprecht, have helped me whenever I have had problems which I could not fix. In particular, conversations with them recently helped me in some formatting issues I was having. I would like to thank them for always being available to ask for assistance, and for giving me nice large-sized monitors.

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I would like to thank Andrew Hamilton for our many conversations, and for suggesting a project relating to the interiors of charged black holes. I do hope that I will be able to complete this project in the near future. This project has allowed me to further stretch my wings and dabble in research areas I would not otherwise have been able to explore.

I would like to thank James Green for taking me on as a teaching assistant in his class on modern cosmology. This prepared me to instruct the class myself the following summer. The experience of designing and implementing a class, which included bells and whistles, was a wonderful experience and only reinforced my desire to teach. I thank Jim for setting me on this path, and I thank Mike Shull of the Astrophysical and Planetary Sciences department for providing me this opportunity.

Additionally I would like to thank Mike Shull and Andrew Hamilton for enabling me to attain my second M.S. degree. However, I could not have done this without the support of Pete and Tuck, and so I thank them for this as well. Tuck has always been supportive of my education, and I appreciate that deeply.

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To my parents for supporting me through hard times, for always encouraging me, and for their everlasting love. I especially would like to thank my father for his comments on this thesis.

Eight years ago, while still in high school, I took an introductory astronomy class at my local university. Prior to taking this class I thought I would become a mathematician, following in my father's footsteps. Possibly turning towards computer science as he did. Although computer science certainly has been a large part of my career to date, I have to thank Alexei Filippenko for opening my eyes to the wonders of the Universe, and for instilling in me a desire to know why the Universe behaves as it does. If it were not for him, I would never have started on this journey.

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