LIGO-M990367-00-M

CaRT (Caltech Relativity Theory Group)
Progress Report to the LSC
February 15, 1999 Through June 15, 1999

A. R&D for Data Analysis

A.d. Search for Coalescing Binaries in 40m Data

Jolien and Teviet Creighton, with former CaRT members Patrick Brady, Scott Hughes, Ben Owen, and Alan Wiseman, and with Bruce Allen and others have completed their manuscript on this search and submitted it to Physical Review Letters [1].

A.f. Behavior of 40m Noise in Matched-Filter Searches for Black-Hole Ringdown Waves

Jolien Creighton's paper reporting the results of this project has been accepted for publication in Physical Review D [2].

A.h. Statistics for Gravity-Wave Searches in NonGaussian Noise

Jolien Creighton's paper reporting the results of this project has been published in Physical Review D [3].

A.i. Excess Power Statistic for Gravitational Wave Burst Searches

This exploration of the properties of Eanna Flanagan's excess-power statistic (being carried out by Jolien Creighton, Patrick Brady [ITP], and Warren Anderson [UWM]) is largely complete and a paper on the results is in preparation.

B. Consequences for LIGO of Source-Modeling Studies

B.a. Interface with Source Modeling Communities

Thorne gave lectures on LIGO-related astrophysics at the ITP (Santa Barbara), Berkeley, Harvard, and the Atlanta American Physical Society meeting, and had a number of private conversations with astrophysicists and relativists about source modeling research for LIGO.

B.b. R-Mode Instabilities in Low-Mass X-Ray Binaries Such as Sco X-1: Implications for LIGO

Levin's paper, reporting on his conclusion that the existence of LIGO-detectable R-mode waves from LMXB's depends critically on the temperature dependence of the viscosity in neutron stars, has been accepted for publication in Physical Review D [4].

Lindblom, with Ben Owen and Greg Mendehl, has extended the theory of R-mode oscillations to include effects second order in the angular velocity and verified that (despite previous worries) the second-order effects do not change the predictions for LIGO significantly [5]

Lindblom, with Greg Mendehl, has initiated a study of the influence of superfluidity on the viscosity of neutron-star matter, with the goal of determining whether the viscosity's temperature dependence is of the sort the Levin finds is needed, for the R-modes to be a promising source for LIGO.

B.c. Nonaxisymmetric Instabilities in Accretion-Induced Collapse of White Dwarf Stars

Our work on LIGO consequences of this source is on hold, awaiting results from further source modeling. That modeling is underway by Liu (a non-LSC effort).

B.d. Tidal Disruption of the Neutron Star in a Neutron-Star / Black-Hole Binary: Consequences for LIGO

Vallisneri has found, using homogeneous ellipsoid models for the neutron star, that the star should be tidally disrupted by the black hole at gravity-wave-inspiral frequencies in the range 300 to 1000 Hz, depending on the masses of the star and hole and the radius of the star. This is a much lower frequency than previous expected, and is low enough to make possible the measurement of neutron-star radii (and thence the neutron-star equation of state) by signal-recycled LIGO-II interferometers. This provides strong motivation for including a flexible, signal-recycled capability in LIGO-II. Vallisneri is writing a paper on this work.

C. R&D for LIGO Facilities and Advanced Detectors

C.a. Gravity Gradient Noise

C.a.i. Seismic Gravity Gradient Noise

Further work on this awaits new seismic measurements at the LIGO sites.

C.a.ii. Human Gravity Gradient Noise

The paper, reporting the results of this project, has been accepted for publication in Physical Review D [6].

C.a.iii. Gravity Gradient Noise from Atmospheric Inhomogeneities and Tumbleweeds

Teviet Creighton found an error in his analysis of the strength of the gravity gradient noise from frozen-in density inhomogeneities carried past the detector by wind. He concludes that for sufficiently smooth air flows, this noise is not strong enough to be a major problem for LIGO-III. He is now studying more complex air flows. Teviet has computed the gravitational signal in LIGO produced when a wind-carried tumbleweed hits the end wall of a LIGO end station. His preliminary conclusion is that the noise is strong enough to be detected in LIGO III up to frequencies of many tens of Hz, and perhaps also in LIGO II.

C.b. Light Scattering Noise

Thorne and Flanagan (Cornell) have delayed work on their Physical Review manuscripts about this research because of greater urgency of other projects.

C.e. Control of Suspension Thermal Noise

This project has been on hold for the past four months.

C.f. Use of LIGO to Search for Narrow Band Waves at 37kHz and its Harmonics

This project (by Levin and Thorne) is still on hold due to other more urgent things.

C.g. QND Interferometer Designs for LIGO-III
[OUR HIGHEST PRIORITY PROJECTS]

The Caltech QND reading group met nearly weekly throughout the 1998-99 academic year. This provided valuable insights for our research, including the following:

C.g.i. Dual-Resonator Speed Meter for Internal Readout of a LIGO Interferometer

Braginsky, Gorodetsky and Khalili [MSU], and Thorne completed their analysis of this speed meter (to which we have given the name ``dual resonator'' because of its reliance on weakly coupled microwave resonators). They conclude that with current technology a demonstration version of this speed meter, operating at ~500 Hz frequency, is feasible, but a robust instrument for LIGO will require technological advances, most especially quality factors for the microwave resonators of $\sim 10^{10}$ or higher. A paper describing this work is nearly finished and will soon be submitted to Physical Review D.

C.g.ii. Speed-Meter-Type Interferometer Design

Braginsky, Gorodetsky and Khalili [MSU], and Thorne, have concluded that this candidate LIGO-III interferometer design can beat the SQL by a factor of about 3 in amplitude with existing mirror-reflectivity technology, but improvements beyond 1/3 SQL will require substantial further reductions in mirror losses. This design requires a light power larger, by $(h_{SQL}/h)^2$ [i.e. a factor 10], than that, W_{SQL}, required to reach the SQL. This is uncomfortably high, but perhaps feasible in the LIGO-III time frame.

These conclusions are still somewhat preliminary. Purdue has embarked on a careful and thorough analysis of this interferometer design, to check these conclusions.

C.g.iii. Conversion of a Conventional Interferometer into a QND Interferometer by Changes of the Input and/or Output Optics

Levin and Thorne, with Kimble (Caltech), Vyatchanin (MSU), and Matsko (Texas A&M), have shown firmly that it is possible (in principle) to convert any conventional interferometer into a QND interferometer (one that can beat the SQL) by modifying the input and/or output optics.

The output modifications entail sending the output light through an optical filter, whose details depend on the internal optics of the interferometer, then performing balanced homodyne detection at a suitable phase. With these modifications, such an interferometer has essentially the same performance as the speed-meter interferometer described above (C.G.ii); it can beat the SQL by a factor 3 in amplitude with current mirror-loss technology but requires an uncomfortably high light power: larger, by $(h_{SQL}/h)^2$ [i.e., a factor 10], than W_{SQL}.

The input modifications are of a sort invented by Caves and Unruh in the early 1980s, but with a necessary new twist. They entail (i) creating squeezed-vacuum light using nonlinear optics, then (ii) passing the squeezed light through the same specially configured optical filter as is needed when one modifies the output optics (a step neglected in previous theoretical studies of this method), and then (iii) ejecting the filtered, squeezed light into the interferometer's dark port. This scheme can beat the SQL by a factor 3 in amplitude with light power that might be as small as W_SQL, rather than 10 W_SQL as for the output-modified scheme and the speed-meter interferometer scheme; but this power is still uncomfortably high.

C.h. Noise Spectra for LIGO-II Including Quantum Behavior of the Test Masses

Braginsky, Gordetsky, Khalili, Matsko and Vyatchanin [MSU] have convinced Thorne that the quantum mechanical behavior of the LIGO test masses is irrelevant to the noise of standard LIGO interferometers. The SQL is enforced in standard interferometers fully and solely by the combination of photon shot noise and light-pressure fluctuations acting on the test masses. Thorne has devised a formal proof of this, based on ideas from his collaborators. This proof shows that quantum mechanical state reduction, as the LIGO data are collected and digitized, has absolutely no influence on the noise. Moreover, a fully classical computation of the noise can give the correct quantum mechanical result, if all light that eventually makes its way into the output beam (e.g., light entering the interferometer's dark port) is treated as having a noise spectral density given by the appropriate electromagnetic vacuum expectation values.

The bottom line of this work is that current classical methods of computing LIGO-II noise curves should give quantum mechanically correct results.

PUBLICATIONS

[1] B. Allen, K. Blackburn, P. Brady, J. Creighton, T. Creighton, S. Droz, A. Gillespie, S. Hughes, S. Kawamura, T. Lyons, J. Mason, B. J. Owen, F. Raab, M. Regehr, B. Sathyaprakash, R. L. Savage, S. Whitcomb, and A. Wiseman, ``Observational limit on gravitational waves from binary neutron stars in the galaxy,'' Physical Review Letters, submitted; gr-qc/9903108.

[2] Jolien D.E. Creighton, ``Search techniques for gravitational waves from black-hole ringdowns'', Physical Review D, accepted for publication; gr-qc/9901084.

[3] Jolien D.E. Creighton, ``Data analysis strategies for the detection of gravitational waves in nonGaussian noise'', Physical Review D, 60, 021101 (1999).

[4] Yuri Leven, ``Runaway heating by R-modes of neutron stars in

X-ray binaries'', Physical Review D, accepted for publication; astro-ph/9810471.

[5] Lee Lindblom, Gregory Mendell and Benjamin J. Owen, ``Second-order rotational effects on the r-modes of neutron stars,'' Physical Review D, accepted for publication; gr-qc/9902052.

[6] Kip S. Thorne and Carolee J. Winstein, ``Human gravity-gradient noise in interferometric gravitational-wave detectors,'' Physical Review D, accepted for publication; /gr-qc/9810016.