# MATTERS OF GRAVITY

The newsletter of the Topical Group on Gravitation of the American Physical Society

**Number 12** **Fall 1998**

## Contents

# Editorial policy:

The newsletter publishes articles in three broad categories,

1. News about the topical group, normally contributed by officers of the group.

2. Research briefs, comments about new developments in research, typically by an impartial observer. These articles are normally by invitation, but suggestions for potential topics and authors are welcome by the correspondents and the editor.

3. Conference reports, organizers are welcome to contact the editor or correspondents, the reports are sometimes written by participants in the conference in consultation with organizers.

Articles are expected to be less than two pages in length in all categories.

Matters of Gravity is not a peer-reviewed journal for the publication of original research. We also do not publish full conference or meeting announcements, although we might consider publishing a brief notice with indication of a web page or other contact information.

# Editor

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# Editorial

I wanted to mention two topics that I find exciting. First, as mentioned in Jim Isenberg's article, the TGG (notice that this is now the official acronym) membership is growing. Becoming a division of APS is starting to appear as less of a dream. I was planning to start a recruitment drive using the newsletter, but at the moment it seems premature. It probably is wise to wait to grow a bit more and then try to go all out to reach that magical 1200 number.

The other topic I wanted to mention is the increasing use of the internet to transmit voice. Concretely, people are starting to record and post on the web conferences and lectures, together with the slides used by the speaker. New audio tools and compression techniques make this feasible even with not too fast network connections. As a token example, the introductory physics lectures I teach at Penn State are on the web. The ITP at Santa Barbara has the whole Strings conference and a bunch of other things online, you can find them at `http://www.itp.ucsb.edu/online`. The Center for Gravitational Physics and Geometry at PSU is posting its semi-weekly talks online, you can listen to them at `http://vishnu.nirvana.phys.psu.edu/relativity_seminars.html`. The importance for research of this tool cannot be understressed. One can keek up with the forefront of research without leaving one's office. In this time of one-conference-every-week, this can be a life saver for physicists who have become road-warriors or for those with limited travel budgets. I will start a link in the TGG's web page to such audio gravity resources, if you know of more, please let me know.

The next newsletter is due February 1st. If everything goes well this newsletter should be available in the gr-qc Los Alamos archives under number gr-qc/yymmnnn. To retrieve it send email to gr-qc@xxx.lanl.gov (or gr-qc@babbage.sissa.it in Europe) with Subject: get yymmnnn (numbers 2-10 are also available in gr-qc). All issues are available in the WWW:
`http://vishnu.nirvana.phys.psu.edu/mog.html`
A hardcopy of the newsletter is distributed free of charge to some members of the APS Topical Group on Gravitation. It is considered a lack of etiquette to ask me to mail you hard copies of the newsletter unless you have exhausted all your resources to get your copy otherwise.

If you have comments/questions/complaints about the newsletter email me. Have fun.

Jorge Pullin

## Correspondents

- John Friedman and Kip Thorne: Relativistic Astrophysics,
- Raymond Laflamme: Quantum Cosmology and Related Topics
- Gary Horowitz: Interface with Mathematical High Energy Physics and String Theory
- Richard Isaacson: News from NSF
- Richard Matzner: Numerical Relativity
- Abhay Ashtekar and Ted Newman: Mathematical Relativity
- Bernie Schutz: News From Europe
- Lee Smolin: Quantum Gravity
- Cliff Will: Confrontation of Theory with Experiment
- Peter Bender: Space Experiments
- Riley Newman: Laboratory Experiments
- Warren Johnson: Resonant Mass Gravitational Wave Detectors
- Stan Whitcomb: LIGO Project
- Peter Saulson; former editor, correspondent at large.

# Topical group news

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Since the summer is a relatively quiet time for TGG activity, not much has happened since the April meeting in Columbus. So most of our news is contained in the following excerpts from the minutes of the Columbus meeting.

1) Officers and Committees.

The list of officers and committee members for the coming year are as follows:

Chair: Abhay Ashtekar

Chair Elect: Rainer Weiss

Vice Chair: Cliff Will

Secretary/Treasurer (1996-1999): Jim Isenberg

Delegates (1998-2001): Steve Carlip, Peter Saulson

Delegates (1997-2000): Lee Samuel Finn, Mac Keiser

Delegates (1996-1999): Frederick Raab, Leonard Parker

Nominating Committee: not yet chosen

Fellowship Committee: Cliff Will, Bill Hamilton, Richard Price

Program Committee: Rai Weiss, David Shoemaker, Beverly Berger

Editor MOG and Webmaster: Jorge Pullin

2) On New Members.

The TGG is a very rapidly growing, at least so far. We have about 530 members. It was noted that if we get to 1200 (which is approximately 3% of the total APS membership) we could qualify as a division. One source of new members we might push is our students.The first year of a student membership is free.

3) Hartle Committee Discussion.

Every ten years, the National Research Council sponsors an in-depth assessment of the past accomplishments, current state, and future prospects of physics research in a number of fields. This year, for the first time, a committee was appointed to prepare a separate book on gravitational physics.. Jim Hartle, who chairs this committee, led a discussion at the general meeting, with the emphasis on soliciting opinions from the members of the TGG regarding the state of gravitational physics research. There was discussion on the adequacy of research support; on interdisciplinary work with data analysis people, math people, computer people, and optics people; on the possibility of instituting summer schools focussing on gravitational physics (like TASI for the particle physics people, and the AMS-run summer schools in math), and a number of other topics. Jim Hartle noted that the deadline for input is essentially the beginning of May, and then the report will be put together.

4) Centenary Meeting.

The next APS "April Meeting" will be in March 1999 in Atlanta, and it will mark the APS' Centenary. This will be the TGG's annual meeting, and plans for the meeting were discussed. We are promised 2 invited sessions, plus one "Centennial Symposium". The "Centennial Symposia" are essentially the same as the focus sessions of this year's meeting, but intended for a broader audience. Beverly Berger will be our liaison with APS in scheduling the Centennial Symposia. Rai Weiss will be our liaison for the general program, including the invited sessions.

There was a report by Phil Lindquist on the proposed display for the Centennial meeting. As approved earlier by members of the Executive Committee, it will focus on gravitational radiation –sources, detection, history of ideas– with LIGO featured. We have been allotted an 8 x 10 space, although we may argue for a bigger space. A rough tentative plan was shown. The tentative cost –$10,000– was discussed. After much discussion, the committee generally agreed to support one third of the cost, up to $3000. LIGO will pay for the rest. Some people noted that the rough sketch of the display contained too much material. All agreed that it will be important to make the display accessible, both to those interested only in a quick perusal, and those who want to learn about gravitational radiation in a bit more detail.

5) Viewpoint on Our Role in APS and These Meetings.

Since the APS meetings are expensive, and consequently not that well attended, the possibility was brought up that we might have the TGG annual meeting at one of the 3 regional meetings on a rotating basis. This issue brought up the question of what the role of the TGG is, regarding the gravitational researcher community, and the rest of the physics community. All at the meeting supported the idea that a major function of this group is to raise the visibility of gravitational physics. This led to strong support for keeping our meeting at one of the large APS meetings. It also led to the view that we have some stake in the continued existence of the April meeting, and that we should be involved in its evolution.

This led to the issue of attracting more people, especially students, to the April APS meetings. There was general agreement that we should spend some of our surplus to provide travel support to students. This could start next year, although no plan for implementing the suggestion was discussed.

6) Prizes

Since last year, some of the members of the Executive Committee have been discussing and researching the possibility of instituting an APS sponsored prize for gravitational physics. Abhay Ashtekar outlined the various possibilities allowed by the APS:

i) Senior Prize: These are tightly controlled by the APS. They want them to be around $10,000, to be awarded at least every other year, and they want very strong assurances that we have 10 years of worthy candidates. So to do this sort of prize would require a lot of paper work, and a lot of fund raising (at least $200,000) ii) Junior Prize: This could be an early career or post-doc award. Less funding and justification is needed. iii) Dissertation Prize: These are not strongly controlled. We could likely institute one without too much work or fund-raising.

While the senior award would take by far the most effort to institute, there was strong support for it. The justification was that it would be the best way to enhance the visibility of the field. Since funding is a big issue, it was decided to pursue discrete, quiet, attempts to locate possible funding sources. Such sources need to be identified before proceeding further with plans to set up a prize.

It was noted that we might also try to set up a junior level prize, but wait on this until the funding inquiries have been made.

# Summer school in gravitational physics opportunity

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In taking input for the Committee on Gravitational Physics one theme which emerged a number of times was the utility of an an occasional or regular Gravitational Physics Summer School.

Some positive arguments for such a school were:

- It would help unify the field.
- It would provide an advanced pedagogical literature.
- In an subject that is becoming increasingly integrated with other parts of physics, it could broaden students and postdocs in the area by acquainting them with developments related areas such as astrophysics and particle physics.
- It would provide a way of introducing the field to students in related areas at universities where there are not strong relativity groups, and perhaps recruiting some talent into the field.

Some of the negative comments were:

- It is not really needed, because, unlike, say particle physics, students do not really need much advanced training to start work on their Ph.D.
- The occasional European schools, e.g. Les Houches 1992, are enough.

The ITP at Santa Barbara is undertaking to help "nucleate" summer schools. What they mean by that is that if suitable outside funding were found, they might run a school once or perhaps irregularly as a kind of demonstration project. They would do the basic local work of arranging accommodation, handling applications, etc which they are set up to do. I spoke to the current director David Gross, and he was receptive, but not of course committal. The next available slot is July 2000, and a competition between proposals will be held at the advisory board meeting February 1999.

However, the ITP does not itself have the funds to run such a school which are of order $50k. That would have to be raised from say the NSF. Rich Isaacson is supportive but not of course committal. He would entertain proposals for the necessary funding, either at the ITP or elsewhere.

What would be needed to take advantage of the opportunity at the ITP is a proposal to them say by November of this year with some understanding from an agency about funding it.

I'd be pleased to discuss this further if it is of interest.

# Bogart, Bergman, and (Al)bert: What might have been

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The recent list of the top 100 American films put out by the American Film Institute places *Casablanca* in the top 10, a ranking few would dispute. Who can forget the haunting song which Ingrid Bergman asked to be "played again", and which brought back such painful memories for Bogart's Rick: "You must remember this, a kiss is still a kiss, ..."?

However, few realize that what was sung in the movie is only part of a song written by Herman Hupfield twelve years earlier. The intro to the song goes as follows[2]:

> This day and age we're living in
>
> Give cause for apprehension
>
> With speed and new invention
>
> And things like fourth dimension
>
> Yet we get a trifle weary
>
> With Mr. Einstein's theory
>
> So we must get down to earth at times
>
> Relax, relieve the tension
>
> And no matter what the progress
>
> Or what may yet be proved
>
> The simple facts of life are such
>
> They cannot be removed
>
> You must remember this ...

What a missed opportunity to connect Albert to Bogie and Bergman!

[1] Robert (Roc) Riemer is currently NRC staff liaison for the Committee on Gravitational Physics.

[2] ©1931 by Warner Bros. Music Corporation, ASCAP

# New data-analysis subgroups of LIGO Science Collaboration

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With the installation of the initial LIGO interferometers only a short year or two from now, the LIGO Science Collaboration (LSC) has started giving more attention to preparing for data analysis. At the LSC meeting in March at the LIGO Hanford site, three new subgroups of the LSC were formed: a *Detector Characterization* subgroup, a *Astrophysical Source Identification and Signatures* subgroup, and a *Detection Confidence and Statistical Analysis* subgroup. These subgroups complement the three previously existing subgroups whose purpose is the design and development of the detectors themselves (the *Stochastic Forces - Isolation and Suspensions*, *Laser and Optics*, and *Interferometer Configurations subgroups*).

Identifying with high confidence a gravitational wave signal in the outputs of the LIGO interferometers will involve several elements: (i) A detailed understanding of the statistical properties of the noise in the instruments, (ii) computationally efficient algorithms to sift through the vast amounts of data generated by the instruments to identify possible candidate signals, with different algorithms for each type of source, and (iii) for each candidate signal, exhaustive post-processing analyses of all available information must be performed in order to assess the probability of it being a true signal. The purpose of the three new subgroups is, roughly speaking, to address these three different tasks.

The Astrophysical Source Identification and Signatures subgroup addresses task (ii) and is chaired by Bruce Allen (ballen@dirac.phys.uwm.edu). More information about this subgroup can be found at its web home-page

`http://www.tapir.caltech.edu/~lsc_asis/`

which contains links to meetings, research plans etc. The Detection Confidence and Statistical Analysis subgroup addresses task (iii) and is chaired by Sam Finn (finn@phys.psu.edu). Finally task (i) is the job of the Detector Characterization subgroup, chaired by Bill Hamilton (hamilton@phgrav.phys.lsu.edu). Individuals who are interested in participating in these groups are encouraged to contact the respective chairmen.

# Marcel Bardon, a man of vision

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Marcel Bardon, Director of the Physics Division of the National Science Foundation and noted photographer, died on May 20, 1998 at age 72, after a courageous battle against lymphoma.

Marcel worked at the NSF since 1970, where he served as the Director of the Physics Division with a few departures to work on international science. His superb scientific judgment, political skill, and extraordinary vision allowed him to substantially advanced the broad frontiers of science. His support for excellent and innovative projects, often in the face of vocal opposition, has had major impact upon many fields. Some of these of particular interest to research in gravity include his creation of the unique Gravitational Physics Program at NSF, the building of the Institute for Theoretical Physics at Santa Barbara, the establishment of the first generation of NSF Supercomputer Centers, and the construction of the Laser Interferometer Gravitational-Wave Observatory (LIGO).

Because of his sensitivity to its future potential, the emerging field of gravitational physics blossomed beyond its traditional theoretical roots. Marcel began NSF support for cryogenic bar detectors when he first came to the Foundation as Program Director for Intermediate and high Energy Physics. With his encouragement as Division Director, expansion of the new Gravitational Physics Program enabled initial R&D on laser interferometers to begin, eventually demonstrating in the laboratory that a large-scale detector was possible. Marcel vigorously championed efforts within the Foundation to proceed with this new technology. His support ultimately lead to approval for the construction and operation of LIGO, the largest scientific project the NSF has undertaken.

Marcel's scientific vision extended well beyond physics, and he possessed a deep understanding of the fundamental nature of science as an international endeavor. During 1979-1981, he served as the Scientific and Technical Affairs Officer with the UNESCO Mission in Paris. From 1986-1988, he was NATO's Deputy Assistant Secretary General for Science in Brussels. He left the NSF Physics Division for an extended tour as the Director of the Division of International Programs during 1992-1997, where he reoriented the division's goals. This lead to its present emphasis on the initiation of new international collaborations and encouragement of the early participation of U.S. scientists in international research.

Marcel's many honors included the NSF Meritorious and Distinguished Service Medals, as well as two presidential awards. He was a Fellow of the AAAS and the APS.

Marcel was born and grew up in Paris. He received a diploma in comparative western literature from the Sorbonne in 1952, then he moved to the United States. Remarkably, he began his study of physics only after enrolling in graduate school at Columbia University. He received his PhD under Leon Lederman in 1961. Marcel worked at Columbia for several years, and was the Deputy Director of the Nevis Laboratory before coming to the NSF.

Marcel enjoyed telling people, with a twinkle in his eye, that physics was only his hobby...his real profession was photography. His sensitive Cibachrome landscapes often explored a deeper vision, revealing a still, timeless, or mysterious side of reality. His work was widely exhibited around the world, including two one-man shows at the Corcoran Gallery of Art in Washington, D.C., as well as exhibits at the Leo Castelli Gallery in New York and the Troyer, Fitzpatrick, Lassman Gallery in Washington, D.C.

Marcel's judgment, leadership, wit, and enthusiasm were an inspiration to all who knew him. He made the world a better place to be in. He will be missed.

# Status of the GEO600 project

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The construction of the GEO600 gravitational-wave detector, a German-British collaboration of the University of Glasgow, the Max-Planck-Institut für Quantenoptik at Garching and Hannover, the Universität Hannover, the Laser-Zentrum Hannover, the Albert-Einstein-Institut Potsdam, and the University of Wales College of Cardiff is well on its way. Short summaries on some aspects of the current work may give an impression of the status of the project.

*Civil engineering:* All the civil engineering work for the buildings and the clean-rooms was finished about a year ago and gives a clean room class in the inner sections of the stations of $< 1000$. A clean tent for obtaining class $<100$ clean-room environment in the vicinity of the tanks is currently being set up.

*Vacuum system:* The vacuum system of GEO 600 approaches completion. Both 600 m long tubes are installed and evacuated. One of them has been baked by passing a DC current of up to 600 A through the tube. The tube got an air bake for two days at about $200^\circ$ C and a vacuum bake at about $250^\circ$ C for a week. The current pressure in the baked tube is at about $10^{-8}$ mbar limited by an air leak which remains to be found. The second tube where the pressure is still dominated by water vapour is already thermally insulated and will be baked in a few weeks time.

The vacuum system in the central station can be separated into two subsystems by a gate valve: 1) The mode-cleaner vacuum system is installed, evacuated, and baked. Currently it is disconnected from the main central cluster and pumped by a separate vacuum pump; 2) The central cluster, where all the tanks are on site and are currently being positioned and anchored.

*Mirror suspensions:* The stacks for the mode cleaner tanks, i.e. three legs per tank of alternating rubber and stainless steel layers that carry a frame structure from which the mirrors are suspended, are manufactured and will shortly be installed. The whole vacuum system of GEO600 is entirely made of metal. To avoid contamination of the vacuum system by the rubber of these stacks they are welded into stainless steel bellows that will be pumped seperately. The suspensions for the mode cleaner mirrors which will be hung as double pendulums is halfway through the workshop.

The stacks for those tanks that will contain the main optics will include an active anti-seismic stage consisting of piezo actuators and geophones in a digital feedback loop. All the hardware is purchased and a suppression factor of about 20 dB has recently been demonstrated in the sub-Hertz frequency range.

The main optics will be suspended as triple pendulums with a monolithic fused silica suspension for the lowest stage. Sufficiently high mechanical Q-factors have been demonstrated by the Glasgow arm of the GEO600 collaboration.

*Electronics:* The local control boards are just moving from the construction into the manufacturing phase. Data communication via a 6 Mbit/s radio link to Hannover and from there into the internet works to our satisfaction. The only difficulty the glass fibre data transport along the interferometer arms encountered were mice who in winter time, for the lack of other food, checked whether glass fibres provide a healthy diet.

*Optics:* The optical layout of GEO600 has been changed from external modulation to Schnupp (frontal) modulation hence avoiding the need of an additional Mach-Zehnder Interferometer at the Michelson output. In addition the control signal for the differential Michelson length control and also the control signal for the signal recycling mirror can be obtained with one modulation frequency by picking up the signals at different locations in the detector. This technique has successfully been demonstrated at the 30 m prototype in Garching.

*Laser:*
In the time it takes the 10 W slave laser to come from a prototype stage to meet the specifications we will use a stabilised 1 W Nd-YAG laser, which works well enough to start with.

Additional information about the status and the schedule of GEO 600 can be found in the GEO 600 web pages: `http://www.geo600.uni-hannover.de`.

# A Nonperturbative Formulation of String Theory?

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Last November, a young theorist named Juan Maldacena made a bold conjecture for a nonperturbative formulation of string theory (hep-th/9711200). He considered spacetimes which asymptotically approach Anti-de Sitter ($AdS$) space and stated that with this boundary condition, string theory is completely equivalent to an ordinary field theory in one less dimension which is conformally invariant i.e. a conformal field theory (CFT). At first sight, this seems crazy – but it is not obviously wrong. When the string theory is weakly coupled and hence well understood, the field theory is strongly coupled, and vice versa. It is well known that perturbatively, string theory has many more degrees of freedom than an ordinary field theory. However, there have been earlier hints from studies of strings at high temperature that fundamentally, string theory should have many fewer degrees of freedom than it appears to. The conformal boundary at infinity of $AdS_n$ is a time-like cylinder $S^{n-2} \times R$. For many purposes, one can think of the field theory as living on this boundary. The most natural field theory to live on this boundary is a CFT since the metric is only defined up to conformal transformations. In a sense, this theory is 'holographic' since the fundamental degrees of freedom live on the boundary, but describe all the physics taking place inside.

There are actually a series of conjectures which differ by the precise asymptotic boundary conditions one imposes on the spacetime. Perhaps the simplest case applies to ten dimensional spacetimes which asymptotically approach $AdS_5 \times S^5$. String theory with this boundary condition is conjectured to be completely equivalent to four dimensional, $U(N)$, $\mathcal{N} = 4$ supersymmetric Yang-Mills theory[1]. The radii of the $S^5$ and $AdS_5$ are equal (i.e., their scalar curvatures are equal in magnitude, but of course opposite in sign) and proportional to $N^{1/4}$ in Planck units. To describe spacetimes with small curvature asymptotically, one needs the radii to be large and hence $N$ to be large.

Maldacena was led to his conjectures by exploring the consequences of the recent description of quantum states of extreme and near extreme black holes in string theory. The near horizon geometry of the extreme Reissner-Nordström solution is $AdS_2 \times S^2$. In higher dimensions, the near horizon geometries of extreme black holes and extended black 'p-branes' are also products of $AdS$ and spheres. It was found a few years ago, that the quantum states of a near extreme black hole could be described in terms of a gauge theory. The gauge theory excitations interacted with the usual string states which described strings propagating further from the black hole. Maldacena argued that if one takes a certain limit which removes the asymptotically flat region around the black hole and focuses on the near horizon geometry, the gauge theory completely decouples from the usual string modes. So it should describe all the physics of strings propagating near the horizon.

Since we do not have another nonperturbative definition of string theory, one could simply take the gauge theory as the definition of the theory[2]. However, to prove the conjecture, one must show that there is an expansion of the gauge theory which reproduces the perturbative expansion of string theory about $AdS_5 \times S^5$. More than twenty years ago, 't Hooft showed that the $1/N$ expansion of a gauge theory indeed resembles a string theory. People are now trying to make this correspondence more precise. It is easy to see that the symmetries agree. The isometry group of

[1] $\mathcal{N} = 4$ means that there are four independent supersymmetry transformations. This is the maximum possible supersymmetry for a gauge theory in four dimensions.

[2] The gauge theory is believed to be well defined non-perturbatively through e.g. a lattice regularization.

$AdS_5 \times S^5$ is $SO(4,2) \times SO(6)$, so perturbative string theory on this background will have these symmetries. Four dimensional Yang-Mills theory is invariant under the conformal group $SO(4,2)$. The $\mathcal{N} = 4$ supersymmetry implies that in addition to the gauge field, there are four fermions and six scalars, all taking values in the adjoint of $U(N)$. There is an $SO(6)$ symmetry which rotates the six scalars, so the bosonic symmetries agree. It turns out that the supersymmetries agree as well.

The low energy string excitations are described by a supergravity theory. It has been shown that the energy of linearized supergravity modes on $AdS_5 \times S^5$ agrees precisely with the energy of states in the gauge theory. This can be verified even though the gauge theory is strongly coupled, since the supergravity states correspond to states in the gauge theory which are protected against quantum corrections. Some perturbative interactions have also been checked and shown to agree. The gauge theory is believed to describe *all* finite energy excitations about $AdS_5 \times S^5$, including black holes. It is clear from earlier work that the gauge theory has enough states to reproduce the entropy of black holes. It is a simple exercise to check that a large five dimensional Schwarzschild-AdS black hole has $S \propto T^3$ and $M \propto T^4$, exactly like a four dimensional field theory.

There is currently a tremendous amount of activity in this area, and the subject is developing rapidly in many directions. For example, Witten suggested that one could break supersymmetry, and use this conjecture to study strongly coupled non-supersymmetric gauge theories ( hep-th/9802150, hep-th/9803131). In fact, a simple picture of confinement is emerging based on the geometry on certain asymptotically AdS spacetimes. Conversely, efforts are being made to use the gauge theory to study black hole evaporation. One immediate consequence seems to be that the evaporation will be unitary, since the underlying gauge theory is unitary and its time is equivalent to the asymptotic AdS time. An application to cosmology has also been suggested (G. Horowitz, D. Marolf hep-th/9805207). I have mentioned only a few of the hundreds of papers which have appeared. There was also a recent discussion in Physics Today (August 1998, p. 20).

# TAMA project update

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TAMA is the Japanese project of building a gravitational wave detector. The detector employs a standard power recycled Fabry-Perot interferometer with an arm length of 300m. It is located on the campus of National Astronomical Observatory in Tokyo. The project started in 1995 with the collaborating efforts of National Astronomical Observatory, The University of Tokyo, Institute for Cosmic Ray Research, Institute for Laser Science, High Energy Accelerator Research Organization, Yukawa Institute of Theoretical Physics, and Osaka University. Miyagi University of Education joined the project later.

In 1997 the facility and the vacuum system were completed. The 10W Nd:YAG laser using the injection locking technique was developed by Sony Corporation. The ring-cavity mode cleaner was installed and checked in performance with the 500mW Nd:YAG laser. In 1998 the one arm cavity consisting of two suspended mirrors was installed and locked using the 700mW Nd:YAG laser with both mirrors controlled in orientation by wave front sensing signals (Ward method). We then installed the other arm cavity, the beam-splitter, and two pick-off mirrors. We are now trying to lock the Fabry-Perot Michelson interferometer. In parallel with this effort, we are connecting the 10W laser to the mode cleaner. In fall 1998 we will combine the 10W laser and mode cleaner with the Fabry-Perot Michelson interferometer. When we increase the sensitivity to a reasonable level in spring 1999, we plan to take data of the detector for one month. We will then install the recycling in the interferometer. We expect to have a full sensitivity of TAMA at the end of 1999.

The mechanism of the excess noise produced in the light transmitted through the mode cleaner at the RF frequency of the transmitted sidebands was well understood, and the noise was well suppressed. This ensures that the excess noise does not preclude the shot noise limited sensitivity of the interferometer.

The one arm cavity was held locking very stably for ten days with only several losses of locking. The wave front sensing signals were well diagonalized for the two mirrors, and used to control the orientation fluctuation of the mirrors.

The absolute length of the 300m arm cavity was measured with the accuracy of 1 micrometer using a new technique, which used the phase modulation sideband transmitted through the arm cavity. The result showed that the motion of the 300m arm cavity was dominated by peaks of 20 micrometers which occurred regularly everyday. It turned out that the peaks were caused by pumping the underground water by a hospital nearby.

We will use a new signal extraction method for the recycled interferometer. In the conventional way it is difficult to get the recycling cavity length signal, because the signal is dominated by the common-mode arm cavity length signal due to its high finesse. It was found that the signal extraction matrix can be diagonalized by optimizing the reflectance of the recycling mirror to the sideband rather than to the carrier. The principle of this method has been already verified in the 3m prototype.

As for the future project after TAMA, Institute for Cosmic Ray Research declared that they have adopted the building of a km-class gravitational wave antenna as the institute's future main project. This greatly increases the chances for a future km-class antenna in Japan.

More information about TAMA can be found at our web site. `http://tamago.mtk.nao.ac.jp/`

# Neohistorical approaches to quantum gravity

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In the old days of quantum gravity work was split between canonical and histories approaches. Since the invention of the Ashtekar formalism [1] and loop quantum gravity [2,3] more than ten years ago, much non-string theory work in quantum gravity was devoted to canonical approaches. The main results of this work have been the discovery that geometrical quantities such as areas and volumes [4,5] are represented by finite operators with discrete spectra, whose eigenstates give a basis of states which may be described in terms of spin networks [6,7]. There have even been rigorous theorems demonstrating that these results must be true of a large class of quantum theories of gravity [8][3].

In spite of these successes, in the last two years there has been a shift back to approaches that emphasize spacetime histories and path integrals. One reason for this has been the realization, following the work of Thiemann [9], that while quantum general relativity may be a finite and well defined theory at the Planck scale, there is evidence that the theory produced by the method canonical quantization does not have a continuum limit which reproduces classical general relativity [10,11]. As a result, the interest of many people turned to the possibility that the dynamics of the spin network states might be described in terms of a histories framework in a way that avoid the difficulties of the canonical approach.

In fact, even before these developments, the first formulation of a path integral framework to describe the dynamics of spin network states had been proposed by Reisenberger [12]. The connection of Reisenberger's proposal to the canonical formalism was then elucidated in papers with and by Rovelli [13,14]. In their proposal, and much subsequent work, the spacetime histories in the path integral are represented as discrete combinatorial structures, as is fitting as the basis states in the spin network representation are themselves largely combinatorial. These combinatorial structures can be often visualized as four dimensional triangulations, with labels associated with the discrete geometrical quantities attached to edges, surfaces and tetrahedra. However, unlike the Regge calculus and dynamical triangulation formulations, the triangulations are not meant as an approximation, but rather as a representation of the discrete structure of quantum geometry which was revealed by the results of the canonical formulation.

One strength of this approach is that it has merged with a set of developments in mathematics, which were also going on for several years. Since the early 1990's Louis Crane and collaborators have been working on extending topological quantum field theory (TQFT) from three to four dimensions [15]. The main goal of this work, so far unrealized, has been to find a combinatorial formulation of the Donaldson invariant. In three dimensions, TQFT relies on powerful and apparently deep connections between topology, combinatorics and representation theory, which are most succinctly expressed in terms of category theory. Crane, Frenkel, Yetter, Baez, Dolan and others have been exploring the idea that four dimensional TQFT's must involve still more intricate and subtle relations between the discrete and continuous, which they refer to as "extended category theory." In all of these theories, a topological invariant is expressed as a sum over labels assigned to various parts of the triangulation of a manifold. Topological invariance is proven by showing that the sum is independent of the choice of triangulation. Such formulations are called "state sum models".

The relationship of this work to quantum gravity came about because several people had noticed

[3]Many people have worked in this area. For the older work I give here only a few representative references and apologize to all those not cited.

that classically general relativity can be understood as arising from a TQFT by the imposition of a constraint local in the fields [16]. Crane thus proposed a program of constructing quantum gravity as a discrete path integral by imposing an analogous constraint on a state sum model of a TQFT [17] This goal has apparently been realized by a recent proposal of Barrett and Crane [18], which has been studied in detail by Baez [19] and others [20]. Such models of quantum gravity were called by Baez, "spin foam models" in homage to the spacetime foam of John Wheeler, and the name seems to have stuck.

One thing that is very impressive about these models is that the amplitudes for the histories do seem to reproduce, history by history, the Regge action for classical general relativity [21], while being derived by a particularly elegant restriction of an expression for a topological invariant. This is good because if such a theory is to have a continuum limit, it must be special so as to avoid the problems which prevent generic non-perturbatively-renormalizable theories from making sense. The fact that these theories are closely related to TQFT's, which by definition have continuum limits, suggest that there is reason to hope that this is the case.

Like the earlier Regge calculus and dynamical triangulation approaches, these new spin foam models of discrete quantum gravity are, so far, Euclidean, in that the histories represent discretizations of a four dimensional manifold of Euclidean signature. One expects that if such theories have continuum limits, they are related to second order equilibrium critical phenomena, of the type searched for in the older models.

An alternative approach to discrete spacetime histories which is intrinsically Lorentzian was then proposed by Markopoulou [22] and versions of it have been studied by several people [23,24,25,26]. In these theories spacetime is a discrete causal set, of the kind studied by Sorkin, Meyers and collaborators [27], and 't Hooft [28], with the additional structure that the causally unrelated sets (discrete spacelike slices) are closely related to the spin network states. Thus, the basic idea of Markopoulou is that spacetime is made of a discrete set of events which correspond to local changes in the spin network states.

The question of the existence of a continuum limit for these kinds of theories has been studied by Abjorn and Loll in the $1+1$ dimensional case [24]. General considerations discussed in [24] suggest that in such theories the continuum limit may be analogous to that found in certain problems in non-equilibrium critical phenomena such as directed percolation, where there are analogues of fluctuating causal structure. The relationship of these causal histories to the Euclidean histories described by spin foam models is also being investigated [25]. The optimistic expectation here is that there will be a non-perturbative analogue of Euclidean continuation that will connect the two classes of theories.

Finally, it should be mentioned, that while new, these developments already show promising links to other approaches to quantum gravity. It is easy to extend the algebras that give rise to the labels so as to incorporate supersymmetry, perhaps giving rise to a non-perturbative formulation of string theory [26,29]. Perturbations of these discrete histories indeed look something like perturbative strings [30]. There are also possibilities that the special forms of the theory may allow the holographic principle to be formulated intrinsically, exploiting the fact that the TQFT's already naturally give finite dimensional state spaces associated with boundaries of spacetime [17] Finally, the categorical framework of the spin foam models may allow connections to be made [31] to the Gell-Mann Hartle, kind of histories formulations [32] as these have also been formulated categorically by Isham [33].

In general the most important feature of these theories may be that they depend on the deep connections between the continuous and discrete, and between the topological and algebraic, expressed in categorical terms in TQFT. These give a possibility of joining relativity and quantum theory at their roots, in a way that addresses both the technical and conceptual questions that have so far stymied all attempts to make a complete background independent formulation of quantum gravity.

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# LIGO Project update

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The Hanford (Washington) and Livingston (Louisiana) LIGO sites are now really the centers of activity for the LIGO Laboratory. The buildings and infrastructure are complete, and both permanent and visiting staff are rapidly on the rise.

The physical installation of the beam tubes is now complete, with all 8km accepted at Hanford, 4km accepted at Livingston, and only 4km to go. The LIGO Lab has started the Hanford "bakeout" in which lengths of the over 1m stainless steel diameter tube is heated by passing current through it ($I^2R$ works!) to drive out residual gas; this is a huge undertaking, with monstrous power supplies, cabling, and power sub-stations which travel from arm to arm and then to Livingston as we bake out the beam tube by 2km sections.

The vacuum equipment which houses the detector itself is now all on-site and in various stages of installation and testing. There are some complications with the large gate valves which segment and separate the beam tube from the vacuum equipment, with research into rubber and bellows and the usual details that make up the whole. This may delay the availability of the entire vacuum system, but there is lots to do that is independent and no significant impact on LIGO's turn-on is anticipated.

Several exciting milestones for the detector have taken place over the last half-year. The seismic isolation stack first article was installed and tested, allowing checks of the fit of the components and a verification of the filtering of seismic noise. Some lessons were learned both in the process of the installation and some manufacturing details which can now be applied to the whole series of isolation systems to follow. The manufacture of the series isolators, and the installation of the structures, is now underway at Hanford.

Another exciting step is the appearance of the Pre-Stabilised Laser equipment (and team!) at the Hanford site. The laser, which has already been built up and tested at Caltech, will be resurrected after shipping over the next few months, and will be turned on this fall.

Many other parts of the detector are turning from dreams into hardware, with optics, suspensions, coupling telescopes, mode-cleaning cavities, and servo systems all deep into fabrication. High-speed computer backbones are running at Hanford. The first integration of multiple subsystems will take place in Fall 98, with light coupled from the Laser into the Input Optics system which the University of Florida is delivering and installing.

The MIT LIGO Lab has moved, in July, from its familiar and favorite quarters in ramshackle Building 20 to a sparkling new space in NW17; it is equipped with a beautiful high-bay space (for a to-be-installed full-scale test interferometer), clean-room air everywhere, and (can you imagine it) carpeting on the office floors. Not so many mice, or much "charm", yet, but a very nice space. The Systems Integration effort including the data analysis group at Caltech has moved also into new quarters in the thin air at the top of the Millikan Library.

Research and Development for the initial detector is finishing up. The work on fringe-splitting at MIT concluded with a test of a digital servo-loop, confirming our ability to control and perform diagnostics with the required dynamic range. At Caltech, the 40m interferometer is allowing tests of alignment and acquisition systems and models.

Research for the next phase of LIGO is heating up. The LIGO Science Collaboration (LSC) now has significant momentum, and planning for data analysis of the initial LIGO run and for the hardware improvements slated for some five years from now are well underway. The last meeting of the LSC, in August, was held at JILA in Boulder, Colorado; the next meeting is to be held at the University of Florida in March '99.

Our schedule calls for shakedown of the interferometers starting in mid-'99, and operation in 2001. Additional information about LIGO, including our newsletter and information about the LSC, can be accessed through our WWW home page at `http://www.ligo.caltech.edu`.

# Gravitational waves from neutron stars: recent developments

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The gravitational waves that bathe the Earth presumably do not vary wildly in strength from year to year. However, our very imperfect understanding of their strengths occasionally does change abruptly, prompted either by new astrophysical observations or by new theoretical predictions and discoveries. Such has been the case in the last year for our expectations for periodic gravitational waves from neutron stars, in two different scenarios: (i) accreting neutron stars in low mass X ray binaries (LMXBs), and (ii) hot, young neutron stars in the first year or so after their formation.

*Accreting neutron stars in LMXBs:*

As is well known, rotating neutron stars can radiate via three mechanisms: (i) non-axisymmetry of the star, (ii) non-alignment between the axis of rotation and a principle axis of the moment of inertia tensor, and (iii) excitation of the stars' normal modes. For mechanism (i), the amount of non-axisymmetry can be parameterized by the equatorial eccentricity $\varepsilon_e = (I_{xx} - I_{yy})/I_{zz}$, where $I_{ij}$ is the moment of inertia tensor and the rotation axis is the $z$ axis. Advanced LIGO interferometers can see non-axisymmetric neutron stars out to $\sim 1$ kpc for $\varepsilon_e \gtrsim 10^{-7}/f_{500}$ with 1/3 year integration time, where the rotation frequency is $500 f_{500}$ Hz (Thorne 1998). The likely values of $\varepsilon_e$ for various neutron star populations are highly uncertain. Aside from the millisecond pulsar population which is highly constrained, we know only that $\varepsilon_e \lesssim 10^{-5}$ (Thorne 1998).

Lars Bildsten has recently given fairly convincing theoretical and observational arguments that many LMXBs like Scorpius X-1 should have values of $\varepsilon_e$ of order $10^{-7}$ or larger and should thus be fairly strong sources (Bildsten 1998). First, recent observations by the Rossi X-Ray Timing Explorer satellite indicate that many of the rapidly accreting stars have spin frequencies clustered near 300 Hz. This is somewhat of a puzzle since the accretion would be expected to spin up the stars to much higher frequencies. Bildsten suggests an explanation for this puzzle: that gravitational wave emission is preventing these sources from being spun up any further, i.e., that all the angular momentum being accreted is being radiated into gravitational waves. The limiting angular velocity then scales as the 1/5th power of $\varepsilon_e$ and is thus fairly insensitive to the amount of non-axisymmetry. Second, Bildsten suggests a specific mechanism for generating the required non-axisymmetry: that lateral temperature gradients due to non-uniform accretion over the surface of the star lead (via temperature-dependent electron capture reactions) to lateral density variations in the crust. The resulting estimated values of $\varepsilon_e$ are of the order $10^{-7}$, consistent with what is required.

The wave strengths for these sources can be predicted directly from the the observed X-ray flux and the inferred accretion rate; the amount of non-axisymmetry (quadrupole) is determined by demanding equality of the spin-up and spin-down torques. The strongest source, Sco X-1, is predicted to be detectable with $\sim 3$ years integration with initial LIGO interferometers (Bildsten 1998). Thus, a priority for the early data runs for LIGO and also VIRGO and GEO will be directed searches for periodic signals from known accreting neutron stars.

*Hot young neutron stars – the* r*-mode instability:*

Just over a year ago, Andersson discovered that the $r$-modes of rotating neutron stars are unstable in the absence of viscosity, for all values of the star's angular velocity (Andersson 1998, see also Friedman and Morsink 1998). The instability is driven by gravitational radiation via the

Chandrasekhar-Friedman-Schutz (CFS) mechanism (Chandrasekhar 1970, Friedman and Schutz 1978), and was reviewed by Sharon Morsink in Issue 10 of Matters of Gravity (Morsink 1997). Over the past year a flurry of papers have explored the dramatic astrophysical consequences of the $r$-mode instability. In this review I'll describe these predicted consequences, and summarize the uncertainties and implications. [For a detailed review of instabilities in rotating stars see Stergioulas 1998].

The picture that is emerging is the following. When a neutron star is first formed it is likely spinning at a substantial fraction of its maximum angular velocity. While the star cools from $\sim 10^{11}K$ to $\sim 10^{9}K$ via neutrino emission over the first few years of its life, the stars' $r$-modes are excited and radiate copious amounts of gravitational radiation, carrying away as much as $0.01M_{\odot}c^2$ of energy and most of the initial angular momentum of the star (Lindblom et al. 1998, Andersson et al. 1998). When the transition to a superfluid state occurs at $T \sim 10^9K$, the star is left with angular velocity of $\Omega = (0.05 - 0.10)\Omega_{\rm max}$, the exact value being somewhat uncertain. Here $\Omega_{\rm max}$ is the maximum allowed angular velocity. The predicted wave strengths are such that these sources could be seen out to the VIRGO cluster ($r \sim 20$ Mpc) with enhanced LIGO interferometers (Owen et al. 1998). This is quite an exciting prospect since the event rate could be many per year.

This scenario is consistent with the inferred spin after formation of the Crab pulsar of about $0.05\Omega_{\rm max}$, and also (within the uncertainties of the predictions) of the initial spin period of $\sim 7\,$ms of the recently discovered young pulsar PSR J0537-6910 (Owen et al. 1998). It also resolves the observational puzzle that neutron stars seem to be formed with rather small spins despite one's expectation of near maximal initial spins due to conservation of angular momentum during stellar core collapse. It rules out accretion-induced-collapse of white dwarfs as a mechanism for forming millisecond pulsars; millisecond pulsars must form instead via accretion in which the temperature never gets hot enough to trigger the $r$-mode instability. Finally, since it now seems more likely than before that typical stellar core collapses involve rapid rotation rates, it improves the prospects of our detecting supernovae.

Turn now to the assumptions and calculations that underlie these predictions. There are two conditions for a mode in a realistic neutron star to be CFS-unstable: (i) The mode must be retrograde with respect to the star but prograde with respect to distant inertial observers, the classical CFS condition. Not all $r$-modes will satisfy this condition (Lindblom and Ipser 1998), but the dominant $l = m = 2$ $r$-mode will do so. A crucial point is that this condition is satisfied for all values of $\Omega$ for unstable $r$-modes, whereas it is only satisfied at large $\Omega$ for the previously considered $f$-modes. (ii) When one measures the mode's energy in the rotating frame, the amount of energy lost to viscous dissipation per cycle must be less than the amount of energy per cycle that gravitational radiation reaction adds to the mode. In other words, the viscous dissipation timescale must be longer than the instability growth timescale. For the original CFS instability, calculations in Newtonian and post-Newtonian gravity (Lindblom 1995) had shown that these conditions are satisfied for the $l = m = 2$ $f$-mode only in a certain region in the $T - \Omega$ plane (where $T$ is the stellar temperature) with $\Omega \gtrsim 0.9\Omega_{\rm max}$ and $10^9K \lesssim T \lesssim 10^{10}K$, where $\Omega_{\rm max}$ is the maximum angular velocity. The dependence on temperature arises due to the strong dependence of the coefficients of bulk and shear viscosity on temperature. Since neutron stars are at temperatures $\gtrsim 10^9K$ only for the first few years after their formation, and since it was not clear that the initial value of $\Omega$ would be $\gtrsim 0.9\Omega_{\rm max}$, the conventional view was that the CFS instability would probably not be important in practice (see, eg, Thorne 1998). This picture changed when the $r$-mode instability was discovered. Two independent calculations in Newtonian gravity using a slow rotation approximation have indicated that the instability region in the $T - \Omega$ plane is much larger for $r$-modes, extending down to $\Omega \gtrsim 0.05\Omega_{\rm max}$ (Lindblom et al. 1998, Andersson et al. 1998).

For a newly born neutron star, the evolution of the stars angular velocity and of the $r$-mode amplitude was solved for by making the following assumptions (Owen et al. 1998): Assume that only the dominant, $l = m = 2$, $r$-mode is relevant. Assume that the mode amplitude grows due to the instability until it saturates at a value of order unity due to nonlinear effects. [The predictions are not very sensitive to the assumed saturated value of the mode amplitude]. Then, use conservation of angular momentum to solve for the spin down of the star. While these assumptions seem reasonable, it will be important to verify the qualitative predictions by numerical calculations that allow for nonlinear mode-mode couplings, perhaps using post-Newtonian hydrodynamic codes. There are also uncertainties related to the values of the viscosity coefficients and the temperature of the transition to superfluidity; investigation into these issues is continuing. However, the overall picture of rapid spindown seems very robust.

To conclude, it is not often that elegant but somewhat arcane aspects of general relativity (like radiation reaction due to current multipoles) have such dramatic astrophysical and observational consequences. Let us hope for many more such discoveries.

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# Perugia Meeting

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The Meeting on Thermal Noise and Low Frequency Noise Sources in Gravitational Wave Detectors took place in Perugia, Italy, on June 4-6.

There has recently been a significant growth of interest in low frequency noise sources in gravitational wave detectors and in particular, thermal noise. This workshop was organized to bring together various international efforts in this field and to discuss current results openly in a workshop format.

All the major international groups were present including: VIRGO, GEO600, LIGO, LIGO science community affiliated groups, TAMA, ACIGA, AURIGA, and Nautilus. The meeting started with a series of review talks on thermal noise.

The rest of the meeting was organized into three main sessions: modelling of thermal noise and low frequency noise sources, materials and geometries for low noise detectors and finally advanced designs.

An informal proceedings will be put together at the end of August and should be available in the fall. More information is available at `http://www.pg.infn.it/virgo/PerugiaWorkshop`. The main conclusions of the talks and discussions will be given here.

It is quite clear that most of the groups agree on models, measurements and predictions. Moreover, it is also evident that traditional designs based on fused silica test masses with metallic suspension wires are reaching their theoretical limits in experimental tests. Unfortunately, these numbers do not give excellent results. The best Q's for fused silica test masses are no more than 2e7 while typically they can be 5e5. Sapphire shows some promise of higher Q's with preliminary measurements in Perth giving Q's of a few 1e7, but hopefully going up to 1e8. This coupled with the higher frequency internal resonances of sapphire make it a better material from a thermal noise performance viewpoint. There still remains, however, the problems of the optical properties of sapphire.

For the pendulum mode, it seems that traditional designs cannot give Q's better than about 1e6. Fused silica suspension wires do give better results with some experiments showing Q's better than 1e7. Unfortunately, this still is not good enough. Fused silica does give an immediate design improvement without going to drastic design changes.

Advanced ideas do offer some hope, but with a few precautions. There are proposals for electrostatic and magnetic suspensions. Many of the bar groups, however, have shown that there are diverse electrical and magnetic loss mechanisms and noise sources that must be considered beforehand. They could significantly affect the performance of these alternative designs. Active suspensions are also a solution for reducing seismic noise, but they require more effort in order to produce fully functional prototypes.

The final solution is to cool the suspension system. While it is not obviously clear that the test mass where laser power is dissipated can be cooled, the suspensions could be cooled to a few kelvin. This offers two advantages. The thermal noise is reduced by a factor of the square root of temperature. Also, many materials (but not fused silica) have better Q's at low temperature. There is only some preliminary ideas of what research should be performed. This could be a good meeting point for the interferometer community to learn from the bar community with its many years experience in cryogenic, low noise experiments.

# Nickel and Dime gravity meeting

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The second Eastern Gravity Meeting (dubbed Nickel and Dime by the organizers, and the sequel to the 1996 New Voices in Relativity meeting [1]) was held at the University of Syracuse on March 28 and 29, 1998. The meeting was hosted by the Syracuse relativity group (Josh Goldberg, Don Marolf, Peter Saulson, and Rafael Sorkin) and most of the organizing was done by post-doctoral fellow Steve Penn. The format of the meeting was identical to the Midwest and Pacific Coast meetings, with 15 minutes given to every speaker.

The meeting brought together approximately 50 participants, of which approximately half were graduate students. The topics covered ranged widely, including numerical relativity (Pablo Laguna, Roberto Gomez, Pedro Marronetti, Grant Mathews), quantum field theory in curved spacetime (Eanna Flanagan, Larry Ford, Ted Jacobson, Wolfgang Tichy), experimental LIGO physics (Peter Csatorday, Gabriela Gonzalez, Andri Gretarsson, Ryan Lawrence, Steve Penn, Peter Saulson, Bill Startin), gravitational waves (Nils Andersson, Serge Droz, Kostas Kokkotas, Eric Poisson), classical general relativity (Arley Anderson, Simonetta Frittelli, Thomas Kling, Bill Laarakkers), and quantum gravity (Chris Beetle, Ivan Booth, Roumen Borissov, Richard Epp, Sameer Gupta, Eli Hawkins, Jim Javor, Kirill Krasnov, Jorge Pullin, David Rideout, Rob Salgado, Wendy Smith, Rafael Sorkin, Sachin Vaidya, Chun-hsien Wu).

Here are some of the conference's highlights. The following discussion is necessarily biased toward those topics I am most familiar with, and I'm afraid it will not do justice to the many good talks on quantum gravity.

Grant Mathews and Pedro Marronetti (Notre Dame) reported on the current status of their numerical work (carried out with Jim Wilson) on close neutron-star binaries [2]. This work has generated quite a bit of controversy over the last couple of years. (See Ref. [3] for many negative papers, and Ref. [4] for positive contributions.) Mathews, Marronetti, and Wilson predict that the central density of the neutrons stars increases as the stars approach each other, sufficiently so that the stars will undergo gravitational collapse when they are still widely separated. This conclusion goes against physical intuition (and the many rebuttals listed in Ref. [3]) which suggests that the stars' mutual tidal interaction should make them *more stable* against gravitational collapse. In the last several months, these authors have been testing their code for possible errors and inconsistencies, and have found none. It will be interesting to see how this all gets resolved in the future.

Nils Andersson (Tübingen) reported on his recent discovery of the $r$-mode instability of rotating neutron stars [5]. This instability results in the rapid spin-down of a young neutron star, and produces a large amount of gravitational waves. Needless to say, this is very exciting, because of the possibility that these waves could be eventually detected by LIGO/VIRGO/GEO/TAMA.

Another interesting presentation was from Ted Jacobson (Maryland), who discussed the relevance of super-Planckian frequencies in the usual derivation of the Hawking effect. He presented recent work carried out with Steven Corley [6], in which a quantum scalar field is put on a one-dimensional lattice in a black-hole spacetime. The lattice provides a natural cutoff in the field's dispersion relation, so that super-Planckian frequencies do not occur. For wavelengths which are long compared with the cutoff, the usual Hawking spectrum is recovered.

Finally, Larry Ford (Tufts) reported on an interesting possibility of amplifying the usual Casimir effect by changing the frequency spectrum of the contributing field modes, which can be done by introducing a dielectric into the problem. As a result of his analysis, Ford finds that a small dielectric sphere in the vicinity of a conducting boundary would undergo a potentially measurable force which oscillates (between attraction and repulsion) as a function of the distance from the boundary.

Overall this was a marvelous meeting, during which students and postdocs met with their peers and talked shop, while their advisors exchanged gossip. Like the Pacific Coast and Midwest meetings, the Eastern Gravity Meeting provides a friendly and informal forum for all workers in gravitational physics. Most importantly, it provides a unique opportunity for graduate students and postdocs to gain experience at giving talks. It serves a very useful purpose, and I wish it a very long life!

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# Second International LISA Symposium

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The Second International LISA Symposium was held at the California Institute of Technology in Pasadena, 6-9 July 1998. The symposium featured sessions on astrophysical sources of gravitational waves detectable by an instrument like LISA, relevant technology, data analysis and updates on other detectors. The oral sessions are summarized below. Proceedings of the symposium will be published by the American Institute of Physics. Bill Folkner, the scientific and local organizing committees, and the supporting staff organized an action-packed symposium.

Charles Elachi (JPL) started off the overview session by citing the importance of LISA in the next decade and the importance of a joint ESA-NASA mission. Al Bunner (NASA) described selected and candidate missions in the Structure and Evolution of the Universe (SEU) program, and the decision-making process for selecting future missions. Rudiger Reinhard (ESA) described the status of LISA within ESA's scientific program and the potential for ELITE, a flight test of LISA technology. Kip Thorne (Caltech) surveyed the astrophysics and fundamental physics that will likely be learned from LISA, and is unlikely to be learned from other observations in the next 10 years. Karsten Danzmann (Hannover) compared and contrasted LISA and ground-based gravitational wave detectors. William Folkner (JPL) described the LISA mission concept, and Robin Stebbins (JILA) summarized LISA's operation and sensitivity.

In the first of two sessions on sources, the focus was massive black holes (MBHs) at cosmological distances. Roger Blandford (Caltech), Doug Richstone (Michigan, IAS), Martin Haehnelt (Cambridge) and Elihu Boldt (GSFC) described theoretical scenarios and observational evidence leading to estimates of MBH binary coalescence rates. Steinn Sigurdsson (Cambridge) surveyed the event rates for the inspiral of stellar remnants into MBHs. The second session on sources included talks by Omer Blaes (U.C. Santa Barbara), Sterl Phinney (Caltech), Ron Webbink (UIUC), Dieter Hils (JILA), and Craig Hogan (Washington). The topics ranged from what we can learn from X-ray sources to discussions of galactic binaries and possible primordial backgrounds.

There were three sessions on technology relevant to LISA. The first, with talks by David Robertson (Hannover), Paul McNamara (Glasgow), Michael Peterseim (Hannover), Martin Caldwell (RAL), Joe Giaime (JILA) and Joe Prestage (JPL), addressed topics in interferometry, optics and timing. In the second technology session, Manuel Rodrigues (ONERA) and Stefano Vitale (Trento) talked about inertial sensors. Sasha Buchman (Stanford) and Mac Keiser (Stanford) described relevant Gravity Probe B technologies, and Dan DeBra (Stanford) surveyed space missions which have used drag-free technology. Salvo Marcuccio (Centrospazio) and Michael Fehringer (Austrian Research Centre) described different technologies for micronewton thrusters. In the last technology session, R. Turner (RAL) and Mike Sandford (RAL) summarized structural, thermal and gravitational studies of the LISA baseline design. Yusuf Jafry (ESTEC), Mark Wiegand (Bremen), David Robertson (Hannover) and Michael Peterseim (Hannover) described the European LIsa TEchnology demonstration satellite (ELITE) mission concept.

Curt Cutler (AEI) and Alberto Vecchio (AEI) led the data analysis session by describing the angular resolution and astrophysical parameter determination of the LISA and OMEGA missions. Eric Poisson (Guelph) described hierarchical search strategies to identify the waveforms of stellar mass black holes spiraling into massive black holes. B. Sathyaprakash (Cardiff) examined a new method to generate improved waveforms for MBH binary inspirals, carry out an efficient search and extract source parameters. A. Sintes (AEI) described a scheme for removing coherent noise, and Alessandra Papa (AEI) described a pattern recognition scheme for identifying unexpected, but continuous gravitational wave signals. Finally, Massimo Tinto (JPL) presented a concept for improving the detection sensitivity of a one arm interferometer at selected Fourier components.

In a session on other gravitational wave detectors, the status of the LIGO, GEO, TAMA, VIRGO and resonant mass gravitational wave detectors was reported by David Shoemaker (MIT), Roland Schilling (MPI Garching), K. Tsubono (Tokyo), Luca Gammaitoni (Perugia) and E. Coccia (Rome), respectively. John Armstrong (JPL) reported on past and future sensitivity in spacecraft tracking experiments. O. Aguiar (INPE, Brazil) reported on the resonant bar program in Brazil.

# JILA Meeting on seismic isolation, test mass suspension, and thermal noise issues for GW detectors

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On August 11 - 12, 1998, about 35 people came to Boulder, Colorado to attend the JILA Meeting on seismic isolation, test mass suspension, and thermal noise issues for GW detectors.

The first session included talks on the measurements of ground noise (Gabriela Gonzalez), seismic low-frequency "pre-isolation" systems (Ken Strain, David Shoemaker, Francesco Fidecaro), gravity noise (Kip Thorne), and an interferometric GW detector experiment from 1970 (Judah Levine). Next, there was a session on test mass suspension systems (Mike Plissy, Norna Robertson), a novel method of thermal noise monitoring and reduction (Yuri Levin), a proposal for cryogenic thermal noise reduction (Warren Johnson), as well as a talk on the use of a metal-insulator-metal diode as sensitive element for an accelerometer (Alessandro Bertolini). The topics for the third session included passive and active seismic isolation in the GW band for LIGO-I (Mark Barton), GEO 600 (Ken Strain), VIRGO (Giancarlo Cella), and for the future (Joe Giaime, Dan Debra).

Immediately afterwards, on August 13 - 15, the third meeting of the LIGO Science Collaboration was held. About 80 collaborators were in attendance.

Barry Barish gave an update on the state of the LIGO construction. LIGO is 85% complete as of August '98. 1999 will see the interferometric detectors installed in the vacuum systems. The system will be commissioned in 2000, engineering tests will be conducted in 2001, and the initial coincidence data runs will begin in 2002. He also gave brief updates on the construction and system test progress at the sites, and summarized the financial and staffing issues within the LIGO Laboratory, and enumerated the membership of the LSC. Raffaele Flaminio, Norna Robertson, and David McClelland presented progress reports on VIRGO, GEO 600, and ACIGA. VIRGO and GEO 600 have start dates in the same approximate time frame as LIGO.

The three leaders of the experimental development groups presented their reports. These groups have been studying the technical issues of future LIGO detector enhancements. The focus was on preparing a white paper for the PAC recommending a coherent research plan for LIGO-related research that will lead to detector upgrades in 2004 and 2008 (or so.) This goal has forced the three groups to consider straw-man designs for the first upgrade and a fairly wide range of possibilities for the second. The first upgrade may include an all fused silica double or triple pendulum similar to the one designed for GEO600, a more powerful laser, some kind of low-frequency active pre-isolation, and higher-quality optics. More massive mirrors and signal recycling are also being considered. The second upgrade will likely need even more challenging technology. This may include cryogenic suspensions and/or monitoring-balancing schemes to suppress thermal noise, lower-frequency isolation, alternative test mass materials with lower optical losses in order to tolerate still more powerful lasers, and signal-tuned or adaptive interferometric length detection schemes to maximize SNR for particular sources. The three presenters were David Shoemaker, Stochastic forces, Isolation Systems, and Suspensions; Eric Gustafson, Sensing Noise - Lasers and Optics; and Ken Strain, Interferometer Configurations. Work is now underway to produce an LSC-wide white paper.

The scientific goals driving the detector upgrade path were discussed during two talks given by Peter Saulson and Kip Thorne. It was pointed out that for NS-NS binary coalescences, most of the contribution to signal-to-noise ratio comes from the trough in the noise curve between the falling pendulum thermal and radiation pressure noise at low frequencies and the rising shot noise at high frequencies, so a detector is optimized for this source by lowering noise in the trough. This is quantified in the form of a detection range for a reasonable source SNR; the initial LIGO's NS-NS range should be approximately to the VIRGO cluster, while the first upgrade ought to improve that by a factor of 5 - 10. Other sources can involve different weighting, and various examples were discussed.

When Rainer Weiss introduced the content of the meeting, he highlighted the need for the LSC experimenters to get more involved with the three data- and astrophysics-oriented analysis groups, especially the Detector Characterization group. Reports from these groups reflected quite a bit of progress over the last six months. The Detector Characterization Group report, given by Daniel Sigg, described the task's organization into data reduction, transient analysis, performance characterization, and the production of simulated data sets. Bruce Allen gave the Astrophysical Signatures group's talk, describing the tasks of using current astrophysical knowledge to determine expected source characteristics, developing algorithms, and developing the software implementation. The Validation and Detection Confidence group report, by Sam Finn, explained this group's role as using the knowledge collected by the previous two groups to determine answers to detection confidence questions by statistical means.

Kathleen Johnson and Zeno Greenwood of the Center for Applied Physics Studies at Louisiana Tech University and Alexander Sergeev of the Institute of Applied Physics in Nizhny Novgorod, Russia, made presentations to the LSC describing their institutions and proposing to join the collaboration. Later in the meeting, during the business meeting of the LSC Council both groups were approved for membership. In addition, the Council appointed a nominating committee, which will begin the process of replacing the current appointed leaders with elected ones.

The conference viewgraphs are available in Acrobat form on the LIGO web site, `http://www.ligo.caltech.edu`.