MATTERS OF GRAVITY

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

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Editorial

Nothing profound to say in this editorial, just to thank the contributors and correspondents that make this newsletter possible and as usual to remind everyone that suggestions for authors/topics for the newsletter are very welcome. I also want to apologize for the delay in publication of this newsletter (it was due the first of the month). It happened due to a major computer problem at our Center. In the midst of the chaos and the rush to get the newsletter out as soon as possible, some errors (additional to the usual ones...) might have entered the newsletter. I apologize for those too.

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 2-8 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 the 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
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- Lee Smolin: Quantum Gravity
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- Peter Bender: Space Experiments
- Riley Newman: Laboratory Experiments
- Warren Johnson: Resonant Mass Gravitational Wave Detectors
- Stan Whitcomb: LIGO Project

April 1997 Joint APS/AAPT Meeting

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For the second year, the Topical Group in Gravitation (GTG) has had a significant presence at this meeting, which took place in Washington, DC, April 18-21, with sponsorship of three invited sessions (two jointly with other groups), two focus (special topics) sessions, and two contributed sessions. The annual GTG business meeting was also held. For those of you who were unable to attend but wish more information than can be found in the summary given below, the abstracts of most of the contributed and invited talks can be found at http://www.aps.org/BAPSAPR97/.

The GTG co-sponsored with the Division of Particles and Fields an invited session "Frontiers of Theoretical Physics." Bob Wald spoke on cosmic censorship. While this topic is normally of interest only to gravitational theorists, you may recall that Kip Thorne's bet with Steven Hawking on this subject made the front page of *The New York Times*. Wald was able to capitalize on this excitement to present an excellent review of the meaning of (primarily weak) cosmic censorship that and whether known counter-examples of naked singularities (including the Choptuik solution) were generic. Again fortuitously, Abhay Ashtekar was able to report on very recent results in which geometrical operators in non-perturbative gravity could be used to compute the quantum states of a black hole. This approach could then immediately be compared with Juan Maldacena's discussion of the microscopic calculation of black hole entropy in string theory using duality and D-branes.

The focus session on "Analyzing Data from Gravitational Wave Detectors" was organized by Bill Hamilton. This represents an important area of interaction between theorists and experimentalists: How to interpret the response of current and future gravitational wave detectors. Sam Finn gave an invited talk on data analysis for gravitational wave detectors emphasizing that one could improve the statistical measure by considering all on-line detectors as a single unit rather than considering each singlely and then looking for coincidences. This new measure would be the probability or likelihood of the combined signal profile. Warren Johnson then gave an invited talk on the lessons learned with regard to data analysis from the Allegro bar detector at LSU. He emphasized that all gravitational wave detectors to date have found non-stationary, non-Gaussian noise sources whose level can be reduced but not eliminated and that these should be treated as a "background" source of signal in the data analysis. Even coincidences between two detectors may not be sufficient to rule out such events. Other topics discussed in this session were searching for burst gravitational waves using nonlinear filtering methods (E. Flanagan), a pulsar search with Allegro (E. Mauceli), a rigorous way to characterize observed coincidences in the absence of signal (A. Morse et al), some novel ways to extend the frequency range of gravitational wave interferometers (R. Drever), using the anelastic aftereffect to study thermal noise in interferometer test masses (M.A. Beilby et al), and elimination of some systematic error sources in Gravity Probe B (G.M. Kaiser et al).

Leonard Parker organized a focus session on black hole formation, evaporation and entropy with several invited talks. Matt Choptuik described critical phenomena in black hole formation. First discovered by Choptuik numerically, the past few years have seen a growth of understanding of the nature of the transition between initial data which collapse to a black hole and those which disperse to infinity. Bob Wald, in an invited talk, argued that the "loss of information" in the Hawking radiation process—pure state to mixed state—was not a violation of quantum theory because the black hole formation followed by evaporation creates a spacetime diagram that is not equivalent to the one in which the black hole never existed. Ted Jacobson continues to consider the issue of the role of field modes above the Planck scale in the Hawking process. Standard derivations require such modes to be present. However, Jacobson reports on calculations showing that it is possible for energy that would in principle come from such modes to appear at lower energies (mode conversion) without seriously altering the thermal spectrum of black hole evaporation. In his invited talk, Larry Ford discussed the role of quantum fluctuations in the stability of black hole horizons. He showed that while quantum effects could perturb the horizon, the effect on the Hawking radiation is small for black holes with masses above the Planck mass. Leonard Parker, meanwhile, showed that in his exactly solvable $1+1$ dilaton gravity model, there is a threshold mass for black hole formation (in contrast to the $3+1$ Choptuik result). Contributions by Eric Martinez on a thermodynamic formalism that incorporates strong gravitational fields and a discussion by David Brown on the role of boundary states in black hole entropy completed this session.

The joint invited session between GTG and the Topical Group on Fundamental Constants and Precision Measurements was again very successful. This time, the emphasis was on "Sensitive Mechanical Measurements and the Detection of Gravitational Radiation." Peter Saulson led off with an overview of how to detect a feeble signal amidst the noise. He emphasized lessons learned from Bob Dicke—perform a null measurement and use modulation to enhance the effect of the signal. Jennifer Logan then described the efforts made over the past several years to reduce the mechanical noise in the LIGO 40 meter detector. She also discussed the use of this prototype in the development of power recycling and other advanced LIGO techniques. Bill Hamilton then gave a talk in which he reviewed the development and progress of the Allegro detector. This device has operated almost continuously for the past 5 years and has given great insight into noise reduction and the problems associated with continuous operation. He also discussed proposed spherical detectors. Finally, Mark Bocko reviewed the state of the art in quantum non-demolition techniques and how they might be applied to the detection of weak forces.

The GTG invited session was entitled "Sources and Detection of Gravitational Waves." Jorge Pullin discussed the "close approximation"—the treatment of two black holes as a single distorted black hole. In second order perturbation theory, the accuracy of the approximation can be studied. Perhaps surprisingly, the analytic results agree quite well with numerical results—for separations larger than one would expect. Bruce Allen reported on calculations of how a stochastic background of gravitational waves might be detectable. He considered the sensitivity of LIGO to such a background. Joan Centrella described recent work on numerical simulations of infalling neutron star binaries and the gravitational radiation they produce. Smooth particle hydrodynamics with Newtonian gravity was used to describe the neutron stars while the quadrupole approximation was used to calculate the gravitational radiation. These approximations allowed many simulations to be run in order to study the dependence of the waveforms and spectra on the parameters of the binary and infall. Finally, David Shoemaker reported on the status of the LIGO construction. The highlights of his talks were photographs of one completed arm at the Hanford site and of the construction progress at both sites. He also described some of the nuts and bolts issues of operation and the development of the laboratory and users group.

There were also two sessions of contributed papers. Highlights included a series of experimental talks on the proposed space-based LISA interferometer (R.T. Stebbins et al), noise reduction using active vibration isolation (J.A. Giaime et al and S.J. Richman et al), a balanced heterodyne detection scheme for signal extraction (K.-X. Sun), and using VLBI for solar system gravitation tests (T.M Eubanks et al). There were also several talks on numerical simulations of close compact binaries (New and Tohline), inspiraling neutron star binaries (Matthews and Marronetti), critical phenomena in a harmonic map model (Liebling and Choptuik), and velocity dominance in Gowdy cosmologies (Berger and Garfinkle). In addition, there were analytic discussions on a prescription for relativistic quantization (C. Vuille) and Cauchy horizon stability in plane-wave spacetimes (Konkowski and Helliwell). Several other experimental and theoretical talks were also given.

Kip Thorne chaired the GTG business meeting which was followed by the business meeting of the LIGO Research Community chaired by Sam Finn.

The Physics Survey and the Committee on Gravitational Physics

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Once a decade, the National Research Council's Board on Physics and Astronomy (BPA) conducts a survey of the fields of physics. The most recent was the eight volume *Physics Through the 1990's* in 1986, familiarly known as the "Brinkman Report" after the chair of the survey committee. This was preceded by the "Bromley Report" in 1972. The BPA is now carrying out a new decadal survey entitled *Physics in a New Era* under a committee chaired by Dave Schramm.

These surveys play an important role in conveying the consensus of the scientific community on past achievements and the future priorities to decision makers in Washington, both in funding agencies and the Congress. They are also an opportunity to strengthen the understanding of physics generally and foster its support. It seems likely that the new survey will be particularly important as it comes at the start of a period of constrained funding for science.

The Committee on Gravitational Physics

The new survey will include a volume on each of the major branches of physics, as well as an overview volume. For the first time there will be a separate volume on gravitational physics prepared by a Committee on Gravitational Physics (CGP). The members of CGP are:

James B. Hartle, Chair, University of California, Santa Barbara
Eric G. Adelberger, University of Washington
Abhay V. Ashtekar, Pennsylvania State University
Beverly K. Berger, Oakland University
Gary T. Horowitz, University of California, Santa Barbara
Peter F. Michelson, Stanford University
Ramesh Narayan, Harvard-Smithsonian Center for Astrophysics
Peter R. Saulson, Syracuse University
Joseph H. Taylor, Jr., Princeton University
Saul A. Teukolsky, Cornell University
Clifford M. Will, Washington University

The first meeting of the CGP will be in Washington on October 7-9, 1997. The committee hopes to have finished its task by summer, 1998.

The objectives of the report are as follows:

- Describe the progress in gravitational physics in the last decade.
- Identify the scientifically promising directions for the next decade, and describe the experimental, observational, and theoretical resources that are required to pursue these directions.
- Describe the relationships of gravitational physics to neighboring areas of science, in particular, astrophysics, particle physics, cosmology, and mathematics.
- Assess the standing of the US effort in gravitational physics relative to that in other countries and identify opportunities for international collaboration.

• Examine career patterns and opportunities for scientists in gravitational physics and assess the implications of these for the support of students, post-doctoral researchers, and faculty.

Input to the Committee

The committee invites input from scientists working in gravitational physics that are related to the above objectives, and the individual members of the committee would be pleased to discuss such input. Input should be sent to the chair by e-mail at `hartle@cosmic.physics.ucsb.edu` or by letter at:

James B. Hartle Department of Physics University of California Santa Barbara, CA 93106

As an aid to focusing input, the following are some of the kinds of questions that the CGP will be seeking answers to. This list is not meant as an opinion poll, and it is not expected that every input will address all questions. What would be most helpful are brief, reasoned arguments supporting definite directions in research and funding. Responses like "X-theory should have the highest priority, Sincerely, Prof. Z " are therefore not helpful. On the other hand, copies of your grant proposals are probably too long and too specific. Please try to be realistic. It is commonly agreed that we are facing an era of constrained support for science, and the best that can be hoped for for the NSF budget is level funding. Even if such projections prove overly pessimistic, it is better to be prepared for underfunding rather than the reverse. Responses concluding that the funding for theoretical gravity should be tripled or that we should construct accelerators at Planck energies are also not helpful.

1. What, in your view, are the most outstanding achievements in gravitational physics in the past decade?

2. What, in your opinion, are the most promising directions for research in gravitational physics in the next decade?

3. What resources – in people and facilities – are needed to realize these opportunities?

4. What are the most persuasive arguments that the nation should allocate these resources in competition with other opportunities in science?

5. What should be the top priorities in the NSF program on gravitational physics, and what should be the lowest priorities, assuming a level or declining budget?

6. Large facilities or projects are becoming increasingly important in some areas of gravitational physics – GPB and LIGO for example. Large facilities like LISA and STEP are proposed. How important are these projects for the progress in gravitational physics and which are the most important?

7. What should be done by funding agencies to improve career opportunities for gravitational scientists, and how important are these improvements compared to preserving the existing core research program?

8. How does the US effort in gravitational physics compare with that in other countries? What are the implications of international competition in the area and what are the desirable opportunities for international collaboration?

9. Theoretical progress in some areas has come to increasingly depend on large computer simulations that require collaborations of many scientists. How important are these efforts, what are the resources required, and what is the best way to organize these efforts.

10. Is there adequate theoretical support for the prediction and analysis of presently planned

and future experiments?

11. To what problems in astrophysics, cosmology, and high energy physics can gravitational physics contribute to and what areas of gravitational physics research, both theoretical and experimental, should be emphasized from this point of view?

12. Should we foster greater cooperation and interaction between high energy theorists and gravitational theorists working on fundamental questions in quantum gravity? If so what is the best way to achieve this?

13. What is your view on the role research in gravitational physics plays in the education of people who go on to do useful things outside the field?

14. What other issues concerning the future of gravitational physics should the CGP address, in your opinion?

Further Information

The BPA website: http://www.nas.edu/bpa
The Physics Survey website: http://www.nas.edu/physsurv.html
The CGP website: http://www.nas.edu/cgp.html

Instability of rotating stars to axial perturbations

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A great wealth of information about the internal structure of neutron stars can be obtained through the study of neutron star oscillations. Just as helioseismology has recently revealed important details of the sun's structure, it may be possible in the fu ture to detect gravitational waves caused by the oscillations of a relativistic star and obtain the star's mass and radius [1]. The possibility of making such exciting measurements underlines the importance of understanding the theoretical details o f the pulsations of neutron stars. Earlier this year Nils Andersson [2] made a surprising discovery while numerically investigating the subset of non-axisymmetric perfect fluid oscillations known as axial perturbations: all axial perturbation s with azimuthal angular dependence $e^{im\phi}$ are unstable when the star rotates, for any value of the star's angular velocity. As a result, all rotating stars are unstable to small perturbations!

It has been known for some time that rotating stars are unstable to gravitational radiation reaction [3,4,5] via the Chandrasekhar-Friedman-Schutz (CFS) instability. It turns out that Andersson's result can be explained by the CFS mechanism, but the way that the instability sets in is different from the usual result which holds for polar perturbations. (Recall that the non-radial fluid velocity field created by a polar perturbation of a spherical star can be expressed as a gradient of a spherical harmonic, while for an axial perturbation it is a cross-product of a radial vector and a polar flow.) For a polar perturbation with fixed value of m, the perturbation is stable for small stellar angular velocity, Ω, until a critical velocity, Ω_c is reached. When $\Omega = \Omega_c$, the perturbation's frequency vanishes as seen by inertial observers. For all angular velocities $\Omega > \Omega_c$, the mode is unstable. Andersson's result is that axial modes are unstable for all $\Omega > 0$.

The difference in critical velocities for the two types of perturbations is really not too surprising. For static stars, axial fluid perturbations are trivial [6] and their frequencies of oscillation must vanish [7]. This implies that the critical angular velocity is zero and that axial modes are unstable for any non-zero angular velocity. Indeed, Papaloizou and Pringle [8] have studied these modes for Newtonian stars (which they call r-modes) and the form of the frequency which t hey calculate conforms to the CFS instability criterion. However, the implied instability of the Newtonian r-modes went unnoticed until Andersson pointed it out [2]. A formal proof of the instability for the general relativistic analogue of t he r-modes in the slow rotation limit is presented in a paper by John Friedman and me [7].

Of what astrophysical significance is this new instability? If the instability's growth time is shorter than the time scale for viscosity to damp it out, the axial mode could be an important source of gravitational radiation. For a $l = m = 2$ axial mode the instability's growth rate scales as $(\Omega\sqrt{R^3/M})^{10}$ (in geometrical units, where $\Omega\sqrt{R^3/M} \ll 1$) while the damping rate due to shear viscosity is independent of Ω. An order of magnitude calculation (which agrees with preliminary numerical results [9]) shows that for a neutron star with a temperature of $10^9 K$, the two time scales are equal when the rotational period is of the order of a millisecond. (Assuming a coefficient of shear viscosity which takes account of superfluid effects [10].) As the star rapidly cools, shear viscosity will increase and quickly damp out the instability. This leaves open some interesting questions for future research. When viscosity is included in a full relativistic computation, do axial or polar perturbations place the lower limit on the angular velocity of neutron stars born with high angular momentum? As the newborn star cools and spins down, is it possible for the star to be in a marginally unstable configuration for a long enough time so that an appreciable amount of gravitational radiation is emitted? We look forward to the resolution of these problems.

References:

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[2] N. Andersson, gr-qc/9706075.

[3] S. Chandrasekhar, Phys. Rev. Lett., **24**, 611 (1970).

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LIGO project status

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Construction continues to move forward rapidly at both LIGO sites (Hanford, Washington and Livingston, Louisiana). At the Hanford site, the civil construction at the site (buildings, roads, power) is nearing completion. At the Livingston site, the main activities are the construction of the buildings and the forming of the concrete foundation along the two arms on which the beam tubes will be installed.

The vacuum system is also moving forward. Chicago Bridge and Iron, the company building the LIGO beam tubes (which connect the vertex and ends of the two arms), has completed the fabrication and installation of all 8 km of beam tube at the Hanford site. The first two 2 km sections have been evacuated and are already at a pressure below 10^{-6} torr. They have now moved their fabrication equipment to a facility near the Livingston site, and are starting to prepare for full production. Our contractor for the fabrication of the vacuum chambers and associated equipment which will be in the located in the buildings, Process Systems International, is nearing completion of all the large chambers and associated hardware for the Hanford site. Installation is expected to start in September.

The staffing of the sites is also starting; approximately 15 LIGO staff are located at the two sites, including Hanford Site Head Fred Raab, who recently moved there from Caltech.

The design of the LIGO detectors is accelerating, with the various detector subsystems split approximately 50-50 between the preliminary and final design phases. Fabrication has started for long-lead items including the test masses and other large optics. Approximately half of the fused silica blanks have been received with the remainder expected before the end of the year; General Optics and the Commonwealth Scientific and Industrial Research Organization are polishing these blanks in preparation for coating. Procurements are underway for a complete first article Seismic Isolation Stack to be built this fall with testing to start in the beginning of 1998.

Lightwave Electronics Corporation, under contract to develop a 10 watt single frequency Nd:YAG laser for LIGO, has completed the design and are starting fabrication of the first unit. An experimental unit used to test the performance of this new design met the key requirements for power, beam quality, frequency and intensity noise.

At MIT, a 5 m long suspended interferometer is being used to investigate the limits of optical phase measurements. This recycled Michelson interferometer operated initially with an Argon ion laser at 514 nm, and demonstrated a sensitivity of 3×10^{-10} rad $\mathrm{Hz}^{-1/2}$. It has now has now been converted to operate with a Nd:YAG laser at 1064 nm. A detailed characterization of the noise in this new configuration will begin soon.

The initial meeting of the LIGO Scientific Collaboration (LSC) was held in Baton Rouge, Louisiana in August. The purpose of this meeting was to form a broader scientific effort to both develop the initial detectors and to pursue research leading to more sensitive future detectors. Twenty groups from five countries, representing a total of 201 collaborators were represented. The most important agenda items were to discuss a charter for the LSC and to form working groups on specific technical topics to coordinate the research efforts of different groups. Rai Weiss (MIT) was appointed as the first spokesperson for the collaboration. The next meeting of the LSC is scheduled for March 12-13 at the LIGO Hanford site.

Additional information about LIGO, including our monthly newsletter and information about the LSC, can be accessed through our WWW home page at http://www.ligo.caltech.edu.

The Search for Frame-Dragging

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Gravitomagnetism has a history that is at least as long as that of general relativity itself. The idea that mass currents might generate the gravitational analogue of magnetic fields, and crude experiments to look for such effects predated Einstein. Soon after the publication of general relativity (GR), Lense and Thirring calculated the advance of the pericenter and line of nodes of a particle orbiting a rotating mass.

The gravitomagnetic "dragging of inertial frames" by rotating matter has played a part in discussions about the meaning and usefulness of Mach's principle, in astrophysical models of jets near accreting, rotating black holes, and in proposals for testing alternative theories of gravity.

It is no surprise then, that substantial effort during the past 30 or so years has gone into trying to measure gravitomagnetism. A recent preprint by Ignazio Ciufolini and colleagues [1] claims to have succeeded.

There are three main effects of gravitomagnetism in the solar-system:

1. *Precession of a gyroscope.* In the field of a body with angular momentum $\vec{J}$, a gyroscope at a distance r precesses with an angular velocity given by $\vec{\Omega}_{\rm gyro} = -\mu(\vec{J} - 3\vec{n}\vec{n}\cdot\vec{J})/r^3$, $(G = c = 1)$ where μ denotes the coefficient of frame dragging (1 in GR, $\frac{1}{2}(1+\gamma+\alpha_1/4)$ in the PPN framework). For a gyroscope in a polar Earth orbit at 600 km altitude, the rate is 43 milliarcseconds (mas) per year.

2. *Precession of orbital planes.* The orbit of a particle is a "gyroscope", whose axis or "node" (intersection of the orbit with a reference plane) will also precess. The rate is given by $\vec{\Omega}_{\rm node} = 2\mu\vec{J}/a^3(1-e^2)^{3/2}$, where a and e are the semi-major axis and eccentricity of the orbit. For a satellite at 5000 km altitude, it amounts to about 31 mas per year.

3. *Precession of the pericenter.* In the field of a rotating body there is an advance of $\dot{\omega}_{\rm pericenter} = -4\mu|\vec{J}|\cos I/a^3(1-e^2)^{3/2}$, where I is the orbital inclination.

Since the early 1960's, measurement of the first effect has been the goal of the Stanford Gyroscope experiment (Gravity Probe B). The goal is to measure the precession of an array of gyroscopes in low Earth orbit to better than one percent. Following years of financial uncertainty, the project was endorsed in 1995 by a panel convened by the National Academy of Sciences [2], and NASA Administrator Daniel Goldin made a firm commitment to the mission. The spacecraft and payload are under construction at Stanford and Lockheed-Martin, and the project is actually slightly ahead of schedule for launch in December 1999 [3].

The paper by Ciufolini *et al.* is based on measuring the second effect, the nodal precession. The original idea was proposed in the late 1950s by Husein Yilmaz, and later embellished by Richard Van Patten and Francis Everitt: measure the precession of the plane of a satellite in polar orbit. The multipole moments of the Earth's gravitational field also induce orbital precession via standard Newtonian gravity, but for polar orbits, the effects vanish. It's crucial to suppress the Newtonian effects, because they amount to about 368 $\cos I$ degrees per year. (At 12 degrees inclination, the precession is 360 degrees per year, permitting sun-synchronous orbits.)

Ciufolini proposed a generalization of the Yilmaz-Van Patten-Everitt idea. Since the effect of the even-order Newtonian multipoles is proportional to $\cos I \times$ functions of $\cos^2 I$, one can cancel the Newtonian effects using two satellites in orbits whose inclinations are supplementary ($I_1 + I_2 = 180^o$). (The Earth's odd-order multipoles, $L = 3, 5 \ldots$ are not important). He then noted that there already existed one satellite for this purpose: the Laser Geodynamic Satellite (LAGEOS), a massive, 60 cm diameter sphere, studded with laser retro-reflectors, which was launched into a nearly circular orbit with $I \approx 110^o$ in 1976, and soon became a central tool in geophysics and geodynamics. Low atmospheric drag, and the centimeter accuracy of laser ranging were key to its usefulness.

All that was needed for a frame-dragging test at around a 10 percent level was a LAGEOS in an orbit of 70^o inclination. Alas, this was not to be, and when LAGEOS II was launched in 1992, geophysical and political criteria dictated $I = 53^o$. Although Ciufolini and others lobbied hard for a LAGEOS III with a suitable inclination, it has not yet materialized.

Nevertheless, Ciufolini and co-workers have argued that the situation is not hopeless. The Earth's multipole moments are known very accurately, from decades of accurate measurements of satellite orbits (including LAGEOS). Moments J_6 and higher are small enough and are known well enough that their effects can be subtracted off. Unfortunately, J_2 and J_4 are not known quite well enough. Thus the effective *measured* nodal precession can be viewed as a linear combination $\Omega^{\rm obs}_{\rm node} = A(I)\Delta J_2 + B(I)\Delta J_4 + C\mu$, where ΔJ_i denote the errors in J_2 and J_4 and μ is the frame-dragging coefficient to be measured. Thus there are two measurables, but three unknowns – it's only in the supplementary inclination case that the $J_2 - J_4$ linear combinations are degenerate, and μ can be determined uniquely with only two observables. Given the two non-supplementary LAGEOS satellites, one needs a third measurable. By happy chance, LAGEOS II turned out to have a decent eccentricity – 0.014, as compared to 0.004 for LAGEOS I. This makes its perigee advance measurable. But the predicted advance has a different dependence on the Earth's moments and on frame-dragging: $\dot\omega^{\rm obs}_{\rm pericenter} = A'(I)\Delta J_2 + B'(I)\Delta J_4 + C' \cos I \mu$. According to Ciufolini *et al.*, this gives the third measurable needed.

But this quantity is the weak link in the chain for several reasons. First, the measured orbital displacements are proportional to $e\dot\omega$ and e is still pretty small, so while the nodal precessions could be measured to 1 mas per year, the pericenter advance was limited to about 10 mas per year accuracy. Second, the effects of the odd-order moments are significant for the pericenter advance. Third, non-gravitational perturbations of the satellite, such as those related to radiation pressure and thermal heating, affect the pericenter advance more strongly than they do the nodal advance. Also, tidal, secular, and seasonal variations in all the moments must be carefully taken into account in both nodal and pericenter precessions. The reported result for μ was 1.1, with a realistic error of about 25 percent ($\mu_{GR} = 1$). By contrast, researchers at the University of Texas argue that, in view of the many error sources, an error of 200 percent is probably more realistic [4].

As in all such satellite experiments, with many corrections to be made and subtle systematic effects to be dealt with, more data and an independent data analysis are called for to see if a LAGEOS I & II experiment can really detect gravitomagnetism. In any case, the NASA relativity mission should be much higher precision (by a factor at least 25), thought admittedly at a much higher price tag.

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[2] Truth in advertising: panel which included the present correspondent.
[3] See http://stugyro.stanford.edu/RELATIVITY
[4] J. Ries, private communication.

Conference of the Southern African Relativity Society

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The Southern African Relativity Society was founded in 1995 at a meeting at the University of Zululand. This, the second conference of the society, was held at the University of South Africa, Pretoria, on 6 and 7 February 1997. The conference was organized by the Council of the society (G.F.R. Ellis (President), A. Beesham, N.T. Bishop, W. Lesame and S.D. Maharaj), with local organizing committee consisting of N.T. Bishop, F.E.S. Bullock and S.D. Maharaj. The conference was funded by the University of South Africa and the Foundation for Research Development.

There were 31 delegates at the conference: mainly from South Africa, but also from Egypt, India, Italy, Malawi, Nigeria, Russia, U.K. and U.S.A. The plenary speakers were R.A. Isaacson (N.S.F., U.S.A.), J.V. Narlikar (I.U.C.A.A., India) and J. Winicour (Pittsburgh, U.S.A.).

Richard Isaacson reported on the LIGO project, which is expected to open a new window on the Universe in about 2001; of course, the interesting things that will be seen through this window are those that are not anticipated. Jayant Narlikar talked about the revival of the cosmological constant, arguing that the standard FRW model does not satisfy the observational constraints imposed by the ages of globular clusters, etc. Jeffrey Winicour discussed the optics of black hole formation, and showed computations of the caustics of the event horizon in the axisymmetric case.

Research in relativity in South Africa is concentrated at three centres: Cape Town, Durban and Pretoria. The best known group is probably that at Cape Town led by George Ellis. Their work is now very much focussed on cosmology, and includes the cosmic microwave background, gravitational lensing, observational cosmology and almost-FRW universes. There are more relativists in and around Durban than in Cape Town, not because there is one large group in Durban, but because there are several universities in the area each with an active interest in relativity. Their interests include symmetries and exact solutions, cosmology and inflation, and computer algebra. The group in Pretoria (led by Nigel Bishop) mainly works on numerical relativity, in collaboration with the Binary Black Hole Alliance in the U.S.A. Other interests include observational cosmology, computer algebra and numerical analysis.

In conclusion, the conference provided a useful opportunity for discussion amongst relativists in southern Africa and other parts of the world. The next conference is scheduled for early 1999 in Cape Town. The Conference Proceedings (participants and abstracts) are available on the world wide web at: http://shiva.mth.uct.ac.za/SARS/

II Warszaw workshop on canonical and quantum gravity

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The canonical quantum gravity community gathered in Warsaw, in June, for the second, but already traditional, Warsaw workshop. A perfect organization, mostly the merit of Jerzy Lewandowski, and a well chosen balance between scientific focus and openings towards nearby areas, have contributed to a dense and exciting meeting. The field is in fibrillation, with excitement, new ideas, and a feel of progress happening; the talks were all packed; and the discussion lively.

By far the largest topic discussed (half of the talks), has been *loop quantum gravity*. On the side of physical results, Kirill Krasnov and Abhay Ashtekar reported substantial progress on the problem of deriving *black hole entropy* from quantum gravity, developing the earlier works on the subject by Krasnov and Rovelli. Surprisingly, the long searched derivation of the black hole entropy formula from quantum gravity has being found, almost simultaneously, in both the current major approaches to quantum gravity: strings and loop gravity. The two derivations have opposite strengths and weaknesses. The string theory one succeeds in computing the precise entropy/area ratio ($1/4\hbar G$), but so far it works only for highly unphysical (extreme or nearly extreme) holes; while the loop derivation works for physical cases such as Schwarzschild, but it does not fix the $1/4\hbar G$ factor (although it is compatible with it).

Four talks were devoted to a novel direction in loop quantum gravity: spacetime covariant versions of the formalism. Mike Reisenberger and Carlo Rovelli showed how one can derive a sum-over-histories formulation of loop quantum gravity from the canonical theory, following earlier ideas by Reisenberger himself and Baez. The resulting theory has the intriguing form of *a sum over topologically inequivalent surfaces in spacetime*. Fotini Markopoulou and Lee Smolin explored Lorentzian versions of this construction. Covariant formalism do not seem to be an appropriate topic for a workshop on *canonical* gravity! But maybe old antinomies as the 4 versus 3+1 views of quantum gravity are finally beginning to evaporate.

The weak side of loop quantum gravity is the dynamics, still much debated. Thomas Thiemann, who has recently given a key contribution by constructing a well-defined hamiltonian operator, described the extension of his results to the *inclusion of matter*. The attractive aspect of this new step is that finiteness of the matter hamiltonian supports the hope that loop quantum gravity could realize the dream of curing ultraviolet divergences. The discussion on the physical correctness of the proposed hamiltonian and its variants focused on the problem of the existence of *anomalies* in the constraint algebra. Roman Jackiw emphasized the importance of the problem by discussing some model theories. Don Marolf reported on an elegant and comprehensive analysis of the constraint algebra by Lewandowski and himself: The algebra closes in most of the proposed versions of the hamiltonian constraint. However, it does not seem to reproduce the classical algebra, and doubts were thus raised on the physical correctness of the proposed operators.

Other aspects of loop quantum gravity were discussed by Jorge Pullin in a comprehensive review of the state of the Chern-Simon state in the theory, including recent results obtained using the spin-network technology, and by Renate Loll, who introduced a novel technique for the computation of the spectrum of the volume.

The second largest topic discussed, after loop quantum gravity, has been the problem of formulating quantum mechanics in a form appropriate for gravity. Jim Hartle reviewed his *generalized quantum theory* emphasizing its numerous applications. Chris Isham discussed the formalism of consistent histories, focusing on the intriguing appearance of *topos theory*, a sophisticated branch of mathematics, at its roots. The difference in mathematical style did not hide the fact that these two speakers were talking about the same formalism. A formalism which has become very relevant for loop quantum gravity, in view of the recent steps towards spacetime, sum-over-surfaces formulations, which fit naturally into the Hartle-Isham quantum mechanics. Chris left Warsaw before giving his final lecture, due to an indisposition; but on my way back from Warsaw I had the fortune of spending a delightful day with him in London, and I can assure anybody who might have worried that he was again in perfect conditions!

Ted Newman illustrated the intriguing *reformulation of general relativity in terms of null surfaces*, recently completed by himself, Frittelli, Kozameh and others, including applications to the quantum theory. Mauro Carfora described his analytical derivation of the existence and location of a critical point in *simplicial quantum gravity.* Abhay Ashtekar presented some puzzling "large" quantum gravitational effects. Peter Hajicek discussed the quantization of $2+1$ gravity.

Other subjects covered, which I can only list here for lack of space, were quantum field theory on curved spacetime (Fredenhagen); θ angles (Landsman); relativistic hydrodynamics (Kijowski); exterior gauge fields (Henneaux); dust (Kuchar) and spherical dust shells (Louko); the canonical structure of homogeneous cosmological models (Kodama); the metric representation (Glikman-Kowalski); cylindrical waves quantization (Korotkin); bianchi type VII models (Manojlovic); spinors' evolution (Massarotti); and quantum cosmology (Barvinski).

The workshop was elegantly concluded by an inspiring talk by Jim Hartle, tiled "Problems for the 21st century": so that everybody, going home, could know what to do. On another general relativity conference in Warsaw, half a century ago, Feynman wrote a famous comment, not too gentle towards the relativists. Times are gone, and gravity is today a focal point of fundamental physics research. Who knows, had he been there, maybe this time Feynman might have been a bit nicer . . .

Alpbach summer school on fundamental physics in space

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Each year a Summer School in an area of space science is held in the picturesque mountain village of Alpbach, Austria. Erwin Schroedinger frequently spent time in the summer in Alpbach, and the main lecture room in the Congress House there bears his name. This year, the space science subject chosen was Fundamental Physics in Space. The school was organized and supported by the Austrian Federal Ministry of Science and Transport, the Austrian Space Agency, the European Space Agency, the national space authorities of the ESA member states, and the European Science Foundation. The Chairman was Johannes Ortner from the Austrian Space Agency.

About 50 graduate students from nine European countries took part in the Summer School. There were 25 lectures presented by scientists interested in fundamental physics and in space. The meeting started with an opening talk by Roger Bonnet, the Science Programme Director at ESA. This was followed by a number of introductory talks covering the early universe, gravitational physics, and the questions that can be addressed by fundamental physics missions. Talks on expected improvements in accelerometers and clocks needed for gravitational physics tests in space also were included.

Four main missions were discussed in the remaining lectures. Two are approved missions that are scheduled for flight. One is the Alpha Magnetic Spectrometer for the detection of antimatter in space and the search for dark matter. It will fly on the Shuttle and on the International Space Station. The other is the Gravity Probe B mission, that will measure relativistic dragging of inertial frames due to the Earth's rotation, and also geodetic precession caused by the Earth's mass.

The other proposed missions have been the subject of international studies, but are not yet approved. One is the Mini-STEP mission, where STEP stands for Satellite Test of the Equivalence Principle. The differential accelerations of pairs of concentric masses will be compared with great precision to determine if the ratio of gravitational to inertial mass is the same for different elements. The other mission is the Laser Interferometer Space Antenna (LISA) for gravitational wave studies. It will inventory thousands of galactic binaries containing compact stars, and look for signals from sources out to cosmological distances that contain massive black holes.

A unique feature of the School is that the students spent about half their daytime hours in workshops, where they studied and prepared proposals for possible future missions. The students broke up into two teams, "coordinated" by Robin Laurance from the European Space Technology Research Center in The Netherlands and Nicholas Lockerbie from Strathclyde University in Glasgow. Each team worked on its mission proposals during the workshops and often for many hours at night, using ten PCs to search for information and carry out their studies. The proposals were presented on the last day of the School at a session chaired by Hans Balsiger, the current ESA Science Program Committee chair.

One team chose to concentrate their efforts on a mission to study MACHOs - Massive Compact Halo Objects. Intensive ground-based measurement programs have detected nearly 100 temporary brightenings of stars in the galactic bulge or the Large Magellanic Cloud due to dark objects passing between them and us causing gravitational lensing. The objective of the space mission would be to detect small displacements of star images as well as brightenings using a 1 m diameter telescope and advanced microchannel plate detectors similar to those being developed for particle physics experiments. The relative timing of pulses from dozens of stars would be determined as a star field was swept across the roughly 10,000 parallel strip channels of the detector by a rotating mirror.

The other team presented studies of five missions, of which three were developed into specific proposals. One proposal was for adding the capability to the Alpha Magnetic Spectrometer to convert neutralinos into detectable gamma-rays with energies of 30 to 300 Gev. If this can be done without losing sensitivity for antimatter detection, it would permit searches for neutralinos from the galactic center, an important dark matter candidate.

The other two proposals were for missions designed to considerably exceed the sensitivity of the LISA gravitational wave mission at frequencies lower than and higher than LISA is optimized for. The "extra low frequency" mission would improve the sensitivity for sources involving supermassive black holes such as those found in active galactic nuclei, and also would improve observations of non-compact galactic binaries. The "medium frequency" mission would have its best sensitivity at frequencies between the optimum frequencies for LISA and for ground-based detectors. It would use multiple bounces between mirrors in the different spacecraft. The main objectives would be to permit observations of neutron star binary coalescence much earlier than possible on the ground, and to look for possible coalescence of few hundred solar mass black holes in dense galactic nuclei.

The Proceedings of the Alpbach Summer School, including descriptions of the missions studied in the workshops, will be published by ESA.

MG8, an experimentalists' summary

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Here is an idiosyncratic selection of highlights of the experimental sessions of the 8th Marcel Grossmann meeting, held in Jerusalem 23-27 June 1997.

Ken Nordtvedt, speaking as chair of a session on gravitational experiments in space, gave a graceful review. He focused on the aspect of experimental gravity that consists of the search for (new) long range fields. This he placed in the context of the general paradigm of physics that all interactions are carried by bosonic fields. From this point of view, the questions facing experimental gravity include the possible existence of non-linear gravity, or of scalar, vector, or tensor fields in excess of those included in general relativity. Nordtvedt then reminded his listeners of the tremendous success Lunar Laser Ranging has had since the Apollo 11 astronauts installed the retroreflector array on the Moon. It is now fully competitive with laboratory experiments as a test of the Equivalence Principle, and is expected to keep pace with improvements of lab experiments to reach sensitivity to possible variations in free-fall at the 1 part in 10^{13} level. Excellent prospects for future improvements in our empirical knowledge could come from two new classes of experiments: high-precision clocks carried through the solar system (especially to the vicinity of the Sun), and laser ranging (instead of radar ranging) to the planets. Coupled with further studies of binary pulsars, Nordtvedt predicted a long life ahead for this branch of experimental gravity.

Experiments to observe the Lense-Thirring effect (dragging of inertial frames by rotating masses) were discussed at several events during the meeting. Ignazio Ciufolini described what could be done with the series of LAGEOS satellites, dense spherical bodies studded with hundreds of corner-cube reflectors that have been placed in high Earth orbit. LAGEOS I and II are already in orbit, with a proposed launch of LAGEOS III sometime in the near future. The L-T effect should make the planes of the orbits of these satellites precess in a characteristic way; Ciufolini has now claimed to have detected such orbit precession at the 25% level. Classical effects from the non-sphericity of the Earth also cause precession, so the claim for the detection of the relativistic effect rests on the assertion that these less interesting effects can be accurately modeled. A lively discussion among the attendees was dominated by a sense of optimism that such modeling could be done well. A plenary talk by Francis Everitt described progress on Gravity Probe-B, by all accounts to be the definitive test of the Lense-Thirring effect. The experiment, originally proposed by Leonard Schiff, involves a slightly different version of frame dragging. GP-B will carry four or five gyroscopes of unprecedented symmetry, the precession of whose spin axes will reveal the dragging of inertial frames. The experimental plan includes a rich mix of diagnostic tests that should give one confidence that precession is due to relativity, and not to unmodelled classical effects. The satellite is now making rapid progress toward completion, with a launch expected some time in the interval Dec 1999 to Oct 2000.

A number of interesting papers were presented at the session on experimental tests of gravity, chaired by Cliff Will. Progress reports on G measurements were presented by three groups. The Wuppertal group has increased its earlier estimates of uncertainty in field mass positioning, and now reports $G = (6.6637 \pm 0.0004 \pm 0.0044) \times 10^{-11}$. Their work continues, with a goal of a $50 - 100$ ppm measurement. The Zürich group, which will measure G by measuring the weight changes of 1 kg masses induced by steel tanks containing 13.5 tons of mercury, reported preliminary results using water instead of mercury: $G = (6.674 \pm 0.001 \pm ?) \times 10^{-11}$, with systematic error yet to be determined (currently estimated to be < 600 ppm). The goal of the group is a 10 ppm measurement. The UC Irvine group, which plans a G measurement with a cryogenic torsion balance using a dynamic ("time of swing") method, reported measurements of the properties of torsion fibers at low temperature suggesting that anelastic fiber properties should not limit the accuracy of such a G measurement at a 10 ppm level or better. Also presented were a $1/r^2$ test (A. Arnsek and A. Cadez) indicating that the ratio of gravitational forces at distances of 30 cm and 100 cm agrees with Newton to about 1 part/thousand, and a progress report on the TIFR equivalence principle experiment, which anticipates sensitivity to $\eta = \frac{\Delta a}{a}$ at a level 10^{-12} next year and 10^{-13} in the future. H.J. Paik described plans for a test for $\sigma \cdot r$ dependent forces such as could be generated by an axion, using a superconducting differential angular accelerometer with target sensitivity more than five orders of magnitude greater than current limits. New space-based equivalence principle tests were suggested by A. Nobili, who suggests that an η sensitivity of 10^{-17} may be achieved with a spring-tethered test mass system rotating with its capsule at 5 Hz, and by B. Lange, who proposes a system of unconstrained concentric spherical shells in a drag-free satellite. Several talks suggested new types of EP tests in the realm of atomic physics. Ken Nordtvedt discussed GR tests that may be made using clocks in solar orbit or a solar probe where redshift measurements can be made in fields U/c^2 much larger than achieved to date, with some scenarios suggesting sensitivity to $\gamma - 1$ at a level as small as 10^{-6} or 10^{-7}, to $\beta - 1$ below 10^{-6}, as well as great sensitivity to the solar J2 and possible EP violation in the form of different rates for clocks with different dependencies on α .

A special Memorial Symposium was held in honor of Robert H. Dicke, who passed away in March of this year. Ken Nordtvedt spoke on Dicke's thinking about Mach's Principle, particularly on whether general relativity sufficiently embodies Mach's idea or instead if something like Dicke's scalar-tensor theory is truer to Mach's vision. Symposium organizer Clifford Will gave an overview of the key experiments carried out during Dicke's long career, including his many contributions to microwave physics and astronomy, his improved Eotvos experiment, his early championing of Lunar Laser Ranging, and his measurement of the solar oblateness. Brandon Carter paid tribute to Dicke's proposal of the key idea that became known as the Anthropic Principle. Francis Everitt spoke movingly of the inspiration he had drawn throughout his own career from the work of Dicke, especially the new Eotvos experiment, as reported both in a preliminary account in Scientific American and in the great 1962 treatise by Roll, Krotkov, and Dicke. He also reminded those in attendance of the influence of Dicke's informal discussion group on gravitational physics at Princeton; in 1957 one of its attendees was a Maryland physicist on sabbatical, Joseph Weber. The session was rounded out by impromptu tributes from R. Cowsik, H.J. Paik, and P. Saulson.

A generous portion of time was allotted to work on the detection of gravitational waves, including sessions of contributed talks on resonant mass detectors, interferometers, and on calculations of waveforms from astrophysics sources. There were also invited talks on various aspects of the experiments given by Ken Strain (GEO and LISA), David Blair (UWA), and Piero Rapagnani (VIRGO).

There were descriptions of several fascinating astrophysical phenomena of obvious interest to relativists. Felix Mirabel gave a beautiful review of the properties objects within our Galaxy that exhibit superluminal motion (sometimes called "microquasars".) These objects appear to be wonderful laboratories in which to test the Rees model of apparent superluminal motion as an effect caused by light-travel-time effects when emitting sources move at relativistic velocities in a direction not parallel to the plane of the sky. Two review talks headlined a contributed session on gamma ray bursts. David Band summarized the whole history and phenomenology of the field since the first discovery of the mysterious events in the 1970s. He was followed by E. Costa's outline of the new discoveries made by the Italian satellite Beppo-SAX, whose multi-waveband instrumentation enabled observers to finally find optical, radio, and X-ray counterparts to the enigmatic sources of the bursts. Now that the cosmological distribution of these objects is apparently confirmed, modelers can focus their attention on the luminous end of the phase space of models, most likely binary neutron stars that collide after spiralling together due to gravitational radiation emission.

Second Edoardo Amaldi Conference on Gravitational Waves

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The second edition of the Amaldi Conference on Gravitational Waves was held in CERN this year from July 1 to July 4 and brought together more than 150 scientists from 13 different countries. Both experimental and theoretical activity were well represented at the conference and great emphasis was put on issues in data analysis. The programme included plenary talks, contributed communications and a large poster session (27 posters), the latter two divided in five topic workshops: sources, instrumentation, non-gaussian noise sources, data analysis and future.

In the past decade a lot of effort has been spent by the resonant bar detector groups to improve sensitivity and duty cycle of their instruments. So, a great success, and in fact one of the highlights of the conference, is the fact that presently there are *five gravitational wave detectors* - all bar antennas - *in continuous operation* in the world: NIOBE, in operation since 1993 at the university of Perth, ALLEGRO, operating since 1991 (with a stop during '95) at Louisiana State University, EXPLORER, taking data since 1990 (with a stop from '92 to '94, apart for a few months during '93), at CERN, NAUTILUS in operation since 1996 at LNF (Frascati, Italy) and the AURIGA detector, at LNL (Legnaro, Italy). The latter, as announced during the conference, had started its first cryogenic run in february '97 and has been in stable operation since then with a best sensitivity around 8 mK. During the conference an agreement was signed among these groups to exchange data regularly on the basis of a common protocol.

The state of the art regarding the construction of the km-sized interferometric antennas projects VIRGO and LIGO, and of the smaller scale interferometers, TAMA 300 and GE0 600 was also reviewed. The schedules of all these projects foresee initial operation by the year 2000.

It clearly emerged that a great deal of effort is being made to predict and model gw signals from astrophysical sources, especially black holes (W.H. Lee, R. Price, C.Palomba). B.S. Sathyaprakash showed that it is possible to approximate wave forms of signals from inspiraling compact binaries so that they overlap with the exact wave-form more than 95.6% thus enhancing the detection probability to more than 90%. Issues regarding signals from *binary systems*, *isolated stars* and *stochastic background radiation* were addressed. G.Schaefer showed how to compute the secular changes of the orbital parameters of a binary system up to order $\frac{1}{c^{10}}$ thanks to ad hoc balance equations between far zone fluxes and near zone losses, A.F.Zahkarov presented estimates of $h \sim 8 \times 10^{20}$ with characteristic frequency at 1 kHz from $R \sim 50$ kpc for gw emission during non spherical evolution of pre-SN in the framework of PN formalism. The results of E.Mueller from a comprehensive study of asymmetric core collapse supernovae predict $h \leq 4 \times 10^{-23}$ for a source at $R \sim 10$ Mpc. M. Gasperini presented predictions on a gravitational wave background from the pre big-bang phase typical of string cosmological model. At frequencies above 1 Hz, and up to about 10^{10} Hz, the expected spectrum lies orders of magnitude (even 10) above that predicted by standard inflation. Upper limits set by data from detectors are still far from constraining the parameters of the model: the most recent data yield $\Omega_{gw} h_{100}^2 \leq 60$ and come from the cross correlation of EXPLORER and NAUTILUS data, whereas the upper border of the predicted value is at $\Omega_{gw} h_{100}^2 \simeq 10^{-6}$. Nevertheless the future is promising because already by cross correlating NAUTILUS, EXPLORER and AURIGA the upper limit could be lowered to $\Omega_{gw} h_{100}^2 \simeq 10^{-3} - 10^{-5}$.

In the data analysis session various topics were discussed. Hierarchical procedures to overcome the demanding requirements on computing resources needed to apply optimal matched filtering to the *search for unknown pulsar signals*, have been presented by X.Grave and P. Astone. There have also been a number of presentations (I.M.Pinto, A. Vecchio) on algorithms to estimate *coalescing binaries* parameters, both for space and ground based experiments. A general point about what statistical approach, if bayesian or frequentist, should be used in gravitational wave data analysis was made by S. Finn in his talk.

Future plans concern both the resonant mass and interferometric detection strategy. In the former category fall the projects for big *spherical detectors*, of enhanced sensitivity and capable of estimating parameters of the incoming radiation (E.Coccia, J.A. Lobo, S. Merkowitz). For detection at high frequencies ($\geq 2kHz$) a *local array* of small multi mode cylinders has been proposed. S. Frasca has presented data analysis strategies for this instrument. In the latter category there is the space bound interferometer *LISA* that could make observations in the $10^{-4} - 10^{-1}$ frequency range for signals from massive black holes and galactic binary stars (J.Hough).

Santa Fe Workshop: New Directions in Simplicial Quantum Gravity

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Much of the most interesting recent progress in quantum gravity concerns approaches that are fundamentally discrete, in the sense that it is assumed from the beginning that space or spacetime is built up out of discrete structures. This summer about 40 physicists working on a variety of such approaches met for two weeks at Saint John's College in Santa Fe to discuss recent progress in these areas. Among the directions that were represented were dynamical triangulations, random surface theory, Regge calculus, causal sets, decoherent histories, topological quantum field theory and lattice and path integral approaches to non-perturbative quantum gravity.

The workshop was sponsored by Los Alamos National Laboratory and organized by Emil Mottola. The structure was informal and allowed much time for discussions that probed the key issues in these areas. Here is a summary of some of the highlights of the meeting. (for more details as well as names and references I refer the interested reader to the conference web site, http://nqcd.lanl.gov/people/emil/sgrav.html.

-Two dimensional random surface theory seems by now to be very well understood. The situation with four dimensional dynamical triangulations is better, and the physics of the different phases is better understood. But the order of the phase transition is still debated, although most participants seemed convinced by recent numerical evidence favoring a weakly first order transition. This led to lively discussion as the standard scenario would imply that only theories with a first order transition may have a continuum limit. However, there were proposals that theories with first order transitions may still have critical behavior. Another possibility discussed was that a second order critical point might be found by varying a parameter associated with the measure of the theory.

-There was lively discussion about the longstanding issue of the relationship between Regge calculus and dynamical triangulations. Unfortunately, most of the main proponents of the Regge calculus approach were absent, so a real resolution was not possible. However, it is clear there has been progress on the issue of the measure of the path integral in Regge calculus.

-There are new and apparently very useful techniques for applying the renormalization group to dynamical triangulations.

-There has recently been a lot of progress in the causal set program. One new idea is that directed percolation models may give examples of causal sets which naturally have low spatial dimension. These make possible a new interchange with statistical physics in which methods from the study of directed percolation and cellular autonota may be applied to elucidate non-perturbative behavior in quantum gravity.

-There are new connections between canonical quantum gravity, causal sets, triangulations and topological quantum field theory.

-Analytical techniques may be applied to quantum gravity to uncover the physics of the infrared behavior. Under certain assumptions this leads to surprising predictions about gravitation at cosmological distance scales. These and other analytical calculations may be compared with the results of numerical simulations, leading to a very healthy interaction of computational and analytical methods.

VII Canadian Conference on General Relativity and Relativistic Astrophysics

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This bi-annual conference took place at the University of Calgary on June 5-7. During the three day conference a total of nine invited talks, thirty-five contributed talks and eight posters were presented. In addition a special session was held in the memory of Ken Dunn whose untimely death earlier in the year was met with great sadness in the Canadian relativity community. Ken Dunn helped initiate this series of conferences which began in 1985 at Dalhousie University in Halifax. During the session held in his memory three talks were presented by Jeff Williams, Tina Harriott, and Eric Woolgar (three people closely with associated Ken). All three talks were devoted to recent results obtained from research on "relativistic kinks".

The invited talks covered a number of different topics. George F. R. Ellis opened the conference with the first invited talk which covered two different aspects of inhomogeneous cosmological models. While issues regarding the Sachs-Wolfe effect and measurement of the Cosmological Background Radiation were of great interest, a lively discussion was generated by a new proposal for a definition of gravitational entropy.

Other invited talks dealing with cosmological subjects were presented by Bernard Carr who reviewed the status of various self-similar solutions that might represent over- and under-dense compact regions in the Universe and by John Wainwright whose talk was devoted to a review of the evolution of the Bianchi Cosmological models and the extent to which they undergo isotropization.

Black holes (and once again gravitational entropy and self-similar solutions) were the topic of discussion by some of the other plenary speakers. Richard Price discussed some recent results that have been obtained using analytic approximation methods to compute the dynamics of axi-symmetric black hole collisions. Jack Gegenberg spoke on gravitational solitons and how they may be used to represent black hole spacetimes and Valeri Frolov presented a model demonstrating how black hole entropy is generated in Sakharov's theory of induced gravity. In addition a complete review of the status of research on critical phenomena in gravitational collapse was presented by Matt Choptuik.

On the observational/experimental side of general relativity Bruce Allen provided a review of the latest results from, and progress being made on the LIGO project, including an overview of the possible sources. In addition, Carol Christian of the Space Telescope Science Institute presented a number of impressive images from the Hubble Telescope and discussed how they have added to our understanding of the universe around us.

Partial financial support for the conference was provided by the Canadian Institute for Theoretical Astrophysics, the Fields Institute for Research in Mathematical Science and the University of Calgary whose generosity was much appreciated. Additional thanks go to Leroy Little Bear (of the University of Lethbridge's Native American Studies Department) who presented an interesting perspective on aboriginal cosmological views during the conference banquet and to Big Rock Brewery of Calgary who provided a special bottling of "Black Hole Ale" which represented the first known industrial application of black hole research.