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.

The next newsletter is due September 1st. If everything goes well this newsletter should be available in the gr-qc Los Alamos archives under number gr-qc/9702010. To retrieve it send email to gr-qc@xxx.lanl.gov (or gr-qc@babbage.sissa.it in Europe) with Subject: get 9702010 (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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The 1997 Joint APS/AAPT Meeting will be held 18-21 April 1997 in Washington, DC and features, among other things, the activities of the Topical Group in Gravitation (GTG) including invited and focus sessions sponsored by GTG, as well as the GTG annual business meeting. The Ligo Research Community will also hold its meeting here.

Invited session speakers and talk titles:

Sources and Detection of Gravitational Radiation (sponsored by the Topical Group in Gravitation):

• Jorge Pullin, Penn State,
"Analytic insights into the collision of two black holes"

• Joan Centrella, Drexel,
"Gravitational Radiation from Inspiralling Binary Neutron Stars

• Bruce Allen, UMW and LIGO,
"Will LIGO Detect a Gravitational Wave Background?"

• David H. Shoemaker, MIT LIGO,
"LIGO: Observatory and Instrument Status"

Frontiers in Theoretical Physics (sponsored by the Topical Group in Gravitation and the Division of Particles and Fields)

• Robert M. Wald, Chicago,
"Gravitational Collapse and Cosmic Censorship"

• Abhay Ashtekar, Penn State,
"Large Quantum Gravity Effects in Unexpected Domains"

• Juan Maldacena, Rutgers,
"Black Holes and String Theory"

Sensitive Mechanical Measurements and the Detection of Gravitational Waves (sponsored by the Topical Group in Gravitation and the Topical Group in Fundamental Constants and Precision Measurement)

• Peter Saulson, Syracuse,
"Internal Friction, Brownian Motion, and General Relativity: Low Noise Mechanics and the Challenge of Gravitational Wave Detection"

• W.O. Hamilton, LSU,
" Resonant Gravity Wave Detectors—What They Have Done and What They Can Do"

• Jennifer Logan, Caltech/LIGO,
" Noise Behavior of the LIGO 40m Interferometer for Gravitational Wave Detection"

• Mark Bocko, Rochester,
" Weak Force Detection Strategies, Where Quantum Mechanics and Gravitation Really Meet!"

The GTG has organized two focus sessions with invited and contributed talks on specific topics of interest to the GTG membership. The first, chaired by Leonard Parker, is on "Black Hole Evaporation, Formation, and Entropy" while the second, chaired by Bill Hamilton, is on "Analyzing Data from Gravitational-Wave Detectors."

The GTG will also organize contributed sessions on other areas of experimental and theoretical gravitational physics.

More details are available on the APS Meetings (`http://www.aps.org/meet/meetcal.html`) web page.

The deadline for contributed abstracts has passed.

TGG News

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• *Election News*

We completed our second election this past November. The results were extremely close! (3 votes out of about 120 determined two of the races) The winning candidates for each contested office are as follows:

Vice Chair: Rainier Weiss Executive Committee (Slot 1): Sam Finn Executive Committee (Slot 2): Mac Keiser These people will take office just before the spring meeting, in April.

• *Press Agent*

The APS is encouraging each unit (ie, each topical group, each division, etc) to set up a procedure for getting interesting news items out to the press. I think that the simplest thing (at least for those of us not used to doing this sort of thing on their own) is for members to send such items to the Sec/Treas (currently me), and then I will forward them with comments to the APS/AIP people whose job it is to publicize physics and to work with the press. Please don't be shy about sending me such items. My e-mail is jim@newton.uoregon.edu, and my fax is (541)346-5217.

• *Centenary Speaker List*

The APS Centenary is coming up in 1999. To help celebrate, the APS is planning to set up a list of top notch speakers who will be called upon to give special colloquia and special public lectures around the country. If you wish to volunteer yourself or anyone else for inclusion on this list, please let me know.

• *Centenary Exhibits*

A large part of the Centenary celebration will focus on the APS meeting held in Atlanta in March of 1999. The APS is soliciting exhibits and displays for this meeting. They would like to have a lot of them. If any of you have any such things to offer, again, please let me know.

• *The Malcolm MacCallum GR Notices*

Malcolm MacCallum very generously maintains an electronic GR news service which comes out monthly. While it is likely that most of us subscribe, it may be that some of you do not. If you do not, but would like to, just send an e-mail with your name and e-mail address and phone and fax to M.A.H.MacCallum@qmw.ac.uk

We all greatly appreciate this generous service.

• *Changing Your Address*

If you are changing your address–electronic or postal–the APS folks (including us at the Topical Group) would like to know. Just send a note to membership@aps.org with the relevant information.

Report from NSF

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The LIGO project is nearing completion. In mid 1999 two interferometers are scheduled to be installed at the Hanford, Washington site and shortly thereafter a third is to be installed at the Livingston, Louisiana site. By the end of 2001 all three interferometers are planned to operate in coincidence with a strain sensitivity of 10^{-21}. In anticipation of the operations phase of LIGO, NSF has been encouraging the scientific community to participate in the use and development of LIGO.

On June 25, 1996, NSF convened the Panel on the Long Range Use of LIGO (henceforth to be called the Panel). The Panel was asked to advise NSF on the policies, procedures and resources required to stimulate and support outstanding investigations at LIGO. The Panel was also asked to comment explicitly on the respective roles of the LIGO Project and the NSF in the organization, review, and funding of the scientific observations and the detector R&D. Thirdly, the Panel was asked to estimate the size of the users community and to advise on the funds that would be required over the next decade for LIGO to be an effective user facility. The Panel members were drawn from several areas of the physical sciences including, of course, gravitational physics, but also including disciplines requiring large facilities. Appearing before the Panel were representatives of groups planning to use LIGO, heads of gravitational wave facilities abroad, and the Chair of the LIGO Research Community.

The Panel made recommendations on organization, procedures, policies, data handling and funding. The Panel's report covers a broad range of issues and includes 13 recommendations. I will discuss only a few of these here. The complete report is available on the Web at http://www.nsf.gov:80/mps/phy/ligorpt.htm.

The Panel began with the premise that the essential near-term priority for LIGO is to achieve a definitive detection of gravitational waves. This achievement will validate the system and inaugurate the field of gravitational wave astronomy. Despite the impressive achievements for the initial LIGO detector, greater sensitivity may still be required for the unambiguous detection of astronomical sources. Even if signals are detected with the initial detector, a greater signal to noise ratio will be required to pursue gravitational wave astronomy. Therefore, in the medium term accompanying and following the commissioning, the LIGO Project must be focused on an aggressive R&D effort to achieve an improvement of 10 to 100 times greater strain sensitivity. The Panel noted that, as part of this effort, it is imperative to develop extended national and international collaborations in order to bring the best possible people, ideas and technologies to bear on the detection of gravitational wave radiation. The Panel recommended that these collaborations be integrated with centralized R&D coordination and LIGO Project management. The collaborations developed during this intermediate term will form the basis of the community that will carry LIGO into the longer term marked by the transition of gravitational wave detection into an observational science.

The Panel recommended that the LIGO Project should evolve from the current single management into two distinct entities: 1) a LIGO Laboratory and 2) a formally organized initial Collaboration. The Laboratory will provide the infrastructure that makes it possible for instruments to be developed, built and operated. The Collaboration will build, commission and exploit the initial detector and develop improvements to enhance its sensitivity. The Panel recommended that the Collaboration devise its own plan for internal governance, including clear procedures for the admission of new members. It will be essential for the Collaboration to have a spokesperson who will communicate with the outside community.

The Panel recommended the formation of a Program Advisory Committee (PAC) to provide advice on the formation of the Collaboration, the acceptance of other collaborators, the selection of R&D projects and the assignment of priorities. The Panel proposed that the PAC be part of the NSF review process for LIGO related proposals.

Following this advice, the NSF recently asked the LIGO Project for its opinion on several pending LIGO-related proposals. In formulating the Project opinion, Professor Barish, head of the LIGO Project, obtained an internal staff review of the proposals and then asked the PAC also to review them. With this action, the PAC review became part of the NSF review process.

All of these pending proposals will also be processed through the normal NSF peer review procedure. The evaluations by the LIGO staff and the PAC will be forwarded to the NSF reviewers. This augmentation of the NSF review procedure appears to be working well and, perhaps with some minor modification, will become the standard for processing LIGO-related proposals.

The Panel on the Use of LIGO recognized that LIGO is a national facility and has an obligation to make its data available to those who can make effective use of them. The Panel also recognized that the detection of gravitational radiation will be of such monumental importance that we can ill afford the report of a false signal.

Therefore, the Panel suggested that community involvement in data handling during the initial stage be achieved by drawing into the Collaboration those who would work directly with the in-house LIGO team in developing data analysis tools. During this stage, data will be given only to the Collaboration and publications will require the approval of the Collaboration and in some cases the LIGO Principal Investigator. The Panel noted that the possibility of developing distributed data products should be considered after gravitational radiation events have been detected and the detectors are well understood.

The Foundation has encouraged the collaboration of outside scientists with the LIGO project first to contribute to the initial detector and second, to address the R&D required to improve its sensitivity. The effective use of NSF resources will involve collaborations with the LIGO Project and later with the Collaboration. These arrangements are being codified through substantive memoranda of understanding (MOUs) among the parties involved. These MOUs are the instruments through which NSF will know that each party understands and agrees to its role and scope of activity and the role of its collaborators.

The development of advanced detectors, those beyond the initial LIGO detector and its enhancements, will also require a coherent effort. Plans for handling such proposals await the formation of the Collaboration and the establishment of proper linkages with the Collaboration and the LIGO Laboratory.

We hear that...

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Several members of the Topical Group on Gravitation were elected APS fellows.

Nominated through the Topical Group on Gravitation:

• Robert Wald, University of Chicago, "For his contributions to the understanding of classical and quantum gravity; especially for his seminal role in the development of a rigorous basis for quantum field theory in curved spacetime."

• Rainer Weiss, MIT, "For his pioneering work in the development of laser-interferometric detectors for gravitational radiation, and his contributions to the study of the spectrum and anisotropy of the cosmic microwave background. "

Nominated through the Division of Astrophysics:

• James Bardeen, University of Washington, "For his seminal contributions to the theory of cosmological density perturbations, relativistic astrophysics, and galactic structure."

• Edmund Bertschinger, MIT, "For his outstanding contributions to theoretical cosmology, especially in the understanding of structure formation in the universe."

Nominated through the Forum for International Physics:

• Rodolfo Gambini, Universidad de la Republica, Montevideo, Uruguay, "For distinguished research in field theory and gravitation, notably on geometrical techniques and the loop representation of gauge theories, and for mentoring theoretical physicists in Latin America."

The complete list of new fellows can be seen in http://www.aps.org/fellowship/96indx.html

General relativity in the global positioning system

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The Global Position System (GPS) consists of 24 earth-orbiting satellites, each carrying accurate, stable atomic clocks. Four satellites are in each of six different orbital planes, of inclination 55 degrees with respect to earth's equator. Orbital periods are 12 hours (sidereal), so that the apparent position of a satellite against the background of stars repeats in 12 hours. Clock-driven transmitters send out synchronous time signals, tagged with the position and time of the transmission event, so that a receiver near the earth can determine its position and time by decoding navigation messages from four satellites to find the transmission event coordinates, and then solving four simultaneous one-way signal propagation equations. Conversely, gamma-ray detectors on the satellites could determine the space-time coordinates of a nuclear event by measuring signal arrival times and solving four one-way propagation delay equations.

Apart possibly from high-energy accelerators, there are no other engineering systems in existence today in which both special and general relativity have so many applications. The system is based on the principle of the constancy of c in a local inertial frame: the Earth-Centered Inertial or ECI frame. Time dilation of moving clocks is significant for clocks in the satellites as well as clocks at rest on earth. The weak principle of equivalence finds expression in the presence of several sources of large gravitational frequency shifts. Also, because the earth and its satellites are in free fall, gravitational frequency shifts arising from the tidal potentials of the moon and sun are only a few parts in 10^{16} and can be neglected.

The Sagnac effect has an important influence on the system. Since most GPS users are at rest or nearly so on earth's surface, it would be highly desirable to synchronize clocks in a rotating frame fixed to the earth (an Earth-Fixed, Earth-Centered Frame or ECEF Frame). However because the earth rotates, this is prevented by the Sagnac effect, which is large enough in the GPS to be significant. Inconsistencies occurring in synchronization processes conducted on the Earth's surface by using light signals, or with slowly moving portable clocks, are path-dependent and can be many dozens of nanoseconds, too large to tolerate in the GPS. Thus the Sagnac effect forces a different choice for synchronization convention. Also, the path of a signal in the ECEF is not "straight." In the GPS, synchronization is performed in the ECI frame; this solves the problem of path-dependent inconsistencies.

Several sources of relativistic effects enter in determining the unit of time, the SI second as realized by the U. S. Naval Observatory (USNO). For a clock fixed on earth, time dilation arising from earth's spinning motion can be viewed alternatively as a contribution, in the ECEF frame, to the total effective gravitational potential which also includes contributions arising from earth's non-sphericity. Earth-fixed clocks placed on the same equipotential surface of this effective field all beat at the same rate. Over the span of geological time, the earth's figure has distorted so that it nearly matches one of these gravitational equipotentials–the earth's geoid at mean sea level. The SI second is defined by the rate of atomic clocks on the geoid. This rate is determined to sufficient accuracy, relative to clocks at infinity, by three effects: time dilation due to earth's spin, and frequency shifts due to the monopole and quadrupole potentials of earth.

In General Relativity (GR), coordinate time, such as is expressed approximately by a slow-motion, weak-field metric, covers the solar system. The proper time elapsed on a moving clock depends on the clock's position and velocity in the fields of nearby masses, and can be computed in terms of the elapsed coordinate time if the velocities, positions, and masses are known. Conversely, the elapsed coordinate time can be computed by integrating corrections to the proper time.

The concept of coordinate time in a local inertial frame is established for the GPS as follows. In the local ECI frame, imagine a network of atomic clocks at rest and synchronized using constancy of c. To each real, moving clock apply corrections to yield a paper clock which then agrees with one of these hypothetical clocks in the underlying inertial frame, with which the moving clock instantaneously coincides. The time resulting from such corrections is then a coordinate time, free from inconsistencies, whose rate is determined by clocks at rest on the earth's rotating geoid.

Relativistic effects on satellite clocks can be combined in such a way that only two corrections need be considered. First, the average frequency shift of clocks in orbit is corrected downward in frequency by 446.47 parts in 10^{12}. This is a combination of five different sources of relativistic effects: gravitational frequency shifts of ground clocks due to earth's monopole and quadrupole moments, gravitational frequency shifts of the satellite clock, and second-order Doppler shifts from motion of satellite and earth-fixed clocks. Second, if the orbit is eccentric, an additional correction arises from a combination of varying gravitational and motional frequency shifts as the satellite's distance from earth varies. This correction is periodic and is proportional to the orbit eccentricity. For an eccentricity of .01, the amplitude of this term is 23 ns. Due to a shortage of computer resources on satellites in the early days of GPS, it was decided that this latter correction was to be the responsibility of software in GPS receivers. It is a correction which must be applied to the broadcast time of signal transmission, to obtain the coordinate time epoch of the transmission event in the ECI frame.

At the time of launch of the first NTS-2 satellite (June 1977), which contained the first Cesium clock to be placed in orbit, there were some who doubted that relativistic effects were real. A frequency synthesizer was built into the satellite clock system so that after launch, if in fact the rate of the clock in its final orbit was that predicted by GR, then the synthesizer could be turned on bringing the clock to the coordinate rate necessary for operation. The atomic clock was first operated for about 20 days to measure its clock rate before turning on the synthesizer. The frequency measured during that interval was $+442.5$ parts in 10^{12} faster than clocks on the ground; if left uncorrected this would have resulted in timing errors of about $38,000$ nanoseconds per day. The difference between predicted and measured values of the frequency shift was only 3.97 parts in 10^{12}, well, within the accuracy capabilities of the orbiting clock. This then gave about a 1% validation of the combined motional and gravitational shifts for a clock at 4.2 earth radii.

At present one cannot easily perform tests of relativity with the system because the SV clocks are actively steered to be within 1 microsecond of Universal Coordinated Time (USNO).

Several relativistic effects are too small to affect the system at current accuracy levels, but may become important as the system is improved; these include gravitational time delays, frequency shifts of clocks in satellites due to earth's quadrupole potential, and space curvature.

This system was intended primarily for navigation by military users having access to encrypted satellite transmissions which are not available to civilian users. Uncertainty of position determination in real time by using the Precise Positioning code is now about 2.4 meters. Averaging over time and over many satellites reduces this uncertainty to the point where some users are currently interested in modelling many effects down to the millimeter level. Even without this impetus, the GPS provides a rich source of examples for the applications of the concepts of relativity.

New and surprising applications of position determination and time transfer based on GPS are continually being invented. Civilian applications include for example, tracking elephants in Africa, studies of crustal plate movements, surveying, mapping, exploration, salvage in the open ocean, vehicle fleet tracking, search and rescue, power line fault location, and synchronization of telecommunications nodes. About 60 manufacturers now produce over 350 different commercial GPS products. Millions of receivers are being made each year; prices of receivers at local hardware stores start in the neighborhood of $200.

What Happens Near the Innermost Stable Circular Orbit?

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In decaying binary systems consisting of neutron stars or black holes, a lot can happen near the *innermost stable circular orbit,* or *ISCO*, as a number of theorists have shown over the last couple of years. A number of questions still remain open though: Where the ISCO is located, what physics determines it, and what observable effects ensue. First of all, the ISCO is not even precisely defined.

For the special case of test particle orbiting around a black hole (or sufficiently compact neutron star) the ISCO is well defined, as we all learned in our relativity courses: at $r = 6M$ for a non-rotating black hole, or $r = M$ for a maximally rotating black hole. But the binary orbit of two massive stars evolves due to gravitational radiation reaction, and the ISCO is really the fuzzily-defined radius where slow orbital shrinkage goes over to rapid plunge. Because energy loss by gravitational waves is a bit inefficient even under the best of circumstances, the orbital shrinkage is probably slow enough that the ISCO is reasonably well defined in practice: For instance, if a distant gravity wave observer plots plots gravity wave amplitude as a function of time, a distinct feature will appear. The "ISCO radius" is a phrase commonly used, but must be deprecated because there is no unique (or at least generally agreed upon) way to measure it invariantly.

Sharpening the issue further is its relevance to the Grand Challenge, as was reported by Sam Finn in MOG8. The first 3D codes able to evolve such a binary must begin near the ISCO, so the numerical relativists need to know where it is, and how to model the system for initial conditions near it. The gravity waveforms observable in LIGO, VIRGO and LISA will depend on this issue (Flanagan & Hughes, gr-qc/9701039), and so may gamma-ray bursts (Rees, astro-ph/9701162).

The purpose of this report is to give a quick and nontechnical introduction to these rapidly evolving issues, along with links to the literature for those who want to delve into the whole story. I have probably missed some references; if so, let me know.

The earliest approach to the ISCO is the post-Newtonian one, which has gone through a long development, most notably by Will and collaborators. Two recent papers which reference this body of work are Lai & Wiseman (gr-qc/9609014), and Will & Wiseman (*Phys. Rev.* **D54**, p.4813, 1996; gr-qc/9608012). If one ignores radiation, the ISCO is well defined here, and if radiation reaction is included, the ISCO is indeed "reasonably well defined" (*Phys. Rev.* **D47**, p.3281, 1993). Sensible answers emerge, but the calculations must be carried to high order, and theoretically speaking it not clear they converge. For binaries involving neutron stars, an important physical effect is the tidal interaction between the two stars, which may disrupt the stars (as pointed out in Newtonian theory by Dai, Rasio and Shapiro, *Ap.J.* **420**, p.811, 1994) before the ISCO is reached, and which also can affect the location of the ISCO.

More recently, Taniguchi and Nakamura (astro-ph/9609009) have developed an analytic method based on fluid ellipsoids and a pseudo-relativistic form of the Newtonian gravitational potential, of the form $GM/(r - r_{pseudo})$. This potential doesn't enjoy a clear justification from GR theory (beyond a reasonably accurate reproduction of test particle orbits) but at least it has the virtue of simplicity. They are able to do a parameter study of tidal effects as a function of orbital compactness, and they clearly show in their models the dividing line between cases where tidal effects dominate in creating the ISCO, and cases where relativistic orbital effects dominate.

Turning to full GR theory, one way to make the ISCO well defined is to put our binary into a large cavity with walls made of a mythical material that perfectly reflects gravity waves, and seek a rigidly rotating configuration of stars and standing waves. (This idea goes back 30 years to Thorne and nonspherical modes of neutron stars.) If the cavity is too big, then the total mass-energy of the standing waves dominates the problem — in the limit of an infinite cavity, we get a non-asymptotically flat spacetime. However, thanks to GW inefficiency, the cavity can be made rather large. The best approach of this kind seems that of Blackburn and Detweiler (*Phys. Rev.* **D46**, p.2318, 1992). When applied to the ISCO radius, though, it gives a value which is much lower than that from any other method.

Another way to define the ISCO precisely is to go to some kind of radiation-less approximation to full GR. (The waves can then be painted in later.) The most ambitious version to date of such an approach is that of Wilson & Mathews (*Phys. Rev. Lett.* **75**, p.4161, 1995), and Wilson, Mathews, & Marronetti (*Phys. Rev.* **D54**, p.1317, 1996; gr-qc/9601017), who numerically construct a family of curved but non-radiating spacetimes containing fully hydrodynamic neutron stars. They find a rather large ISCO radius — in fact, large enough that the orbital angular momentum J still exceeds M^2, where M is the total mass-energy of the binary system, so that the stars are forbidden to plunge directly to a Kerr black hole! Another important result comes out of their work: The neutron stars themselves may go radially unstable and begin collapsing to black holes, before the ISCO is reached. The neutron star binary problem may reduce itself to the black hole binary problem! If so, matter is removed from the game, and cannot carry angular momentum to infinity, or help make gamma ray bursts. Again, however, it's not clear how good the approximation is. For further aspects see gr-qc/9512009, gr-qc/9601019, gr-qc/9603043, gr-qc/9701033.

As should be clear, a number of resourceful groups have studied this problem by an amazing variety of methods, none rigorous to date — and it is sometimes hard to inter-compare results. Here is a suggestion: Everyone at work on this problem will benefit if all groups report, at a minimum, the invariant observables M, J, and Ω (noting that quadrupole gravity waves will show up at 2Ω), for each orbital configuration, and especially for the ISCO:

Invariant Quantity	**Dimensional**	**Normalized**
Binding Energy	$M - M_\infty$	$(M - M_\infty)/M_\infty$
Orbital Angular Velocity	Ω	ΩM_∞
Total Angular Momentum	J	J/M_∞^2

For a given binary, the evolutionary sequence of orbital configurations *should* obey the Thorne-Zel'dovich law, $dM = \Omega dJ$. I say *should* rather than *does*, because to my knowledge no-one has proved this law for configurations which are not strictly stationary, rigidly rotating, asymptotically flat solutions of the full Einstein equations — so binaries are not yet covered, and in particular, radiation-less schemes are not yet covered. This provides a good sanity check on the numerical calculations, assuming validity. To prove more general validity poses a good research problem.

In summary, here is a list of important questions that remain open:

1. Do real neutron stars *disrupt*, or *collapse to black holes*, or *neither*, before the ISCO?

2. How much matter (neutrinos, electromagnetic fields, relativistic jet or wind, excretion disk) gets left behind from a coalescing neutron star binary?

3. Do real (say, initially non-rotating) black holes reach the ISCO while the total J is too big for any Kerr black hole, $J > M^2$? — If so, do unexpected GW signals emerge after the ISCO to carry off the excess J?

4. Same question for real neutron stars. In this case, does matter or gravity waves carry off most of the excess J?

Journées Relativistes '96

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The Journées Relativistes were started in the 1950's as an annual meeting of French-speaking relativists and cosmologists. In recent years they acquired a more international flavor, visited various countries in Europe, and adopted English as their lingua franca. The general purpose of these meetings is to report on progress in general relativity and its applications, and to strengthen international scientific cooperation. The major issues of the 1996 conference included general relativity, new developments in cosmology (driven by recent observational results of the CMB and by gravitational lensing) numerical relativity, quantum cosmology and quantum gravity.

The local Organizing Committee of the XXVIth meeting consisted of Ruth Durrer (Geneva), Petr Hájíček (Bern), Philippe Jetzer (Zurich), George Lavrelashvili (Zurich), Mairi Sakellariadou (Geneva), and Norbert Straumann (Zurich), Chairman.

The meeting could not have taken place without the financial support of the ETH Zurich, the Swiss National Science Foundation, the Dr. Tomalla Foundation, and the Hochschulstiftung of the University of Zurich.

The Journées Relativistes '96 were held May 25-30 at the Centro Stefano Franscini on Monte Verità in Ascona, Switzerland, a center for small conferences providing accommodations, lecture hall, discussion rooms, meals, and spectacular views of Lago Maggiore. The seventy-five participants came from fifteen countries, representing all major centers of research in Europe, as well as representatives from South Africa, Israel, Georgia, Russia, Mexico, Canada and USA. Extensive interaction between the participants was fostered by the scheduling, which included adequate discussion time, and the accommodations that allowed everyone to be in the same location; even during evening excursions into the village colleagues were not hard to find.

The main lectures were held by B. Carr (London), P. Chrusciel (Tours), T. Damour (Bures-sur-Yvette), S. Deser (Brandeis U), R. Durrer (Geneva), J. Fröhlich (Zurich), M. Heusler (Zurich), O. Lahav (Cambridge), A. Lasenby (Cambridge), V. Mukhanov (Zurich), G. Neugebauer (Jena), A. Rendall (Potsdam), C. Rovelli (Pittsburgh), P. Schneider (Garching), E. Seidel (Potsdam) and G. Veneziano (CERN). In addition, over forty shorter contributions were given in two parallel sessions. The lectures and contributions have been published in Helvetica Physica Acta, Vol. 69 (1996), Nos 3 & 4.

The Journées also included a visit to a nearby solar observatory, and one afternoon was reserved for an excursion and banquet. This involved a variety of activities hard to find in one place except in Switzerland: boat rides, a sub-tropical island, a hike in the mountains, and dining al fresco.

The XXVIth Journées continued the tradition of a very high scientific and cultural level, and we expect many further, interesting meetings to come in this series.

TAMA Workshop

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The TAMA Workshop on Gravitational Wave Detection November 12-15, 1996, Saitama, Japan

Gravitational wave detection specialists from around the world braved the fearsome Tokyo evening rush hour on Monday, November 11, to reach the idyllic National Women's Education Center at Musashi-Ranzan for the first TAMA Workshop. The meeting was planned as a coming out party for TAMA300, Japan's debutante in the present season of large interferometer construction. Although rather petite for its class (the "300" refers to the instrument's 300 meter arms), its many charms were well displayed to those in attendance. And before the meeting had concluded, there was specific discussion of plans for a strapping 3 km sister instrument hoped to follow in a few years.

Talks at the meeting focused on progress around the world in technologies necessary for successful detection of the feeble waves carrying across cosmic distances the messages of the violent deaths of stars or compact binary systems, or perhaps the birth cries of black holes. While proceeding rapidly, interferometer design will have to hurry to keep up with the breakneck pace that the large construction efforts have achieved. Notably, at this meeting the reports from all of the world's approved large projects (LIGO, VIRGO, GEO 600, and TAMA300) included photographs of large quantities of concrete, in some cases still wet but in all cases demonstrating the fruition of plans many years in the making. A glance back at this decades-long history would have been enough to bring tears to one's eyes, were it not for the bracing beauty of the promise of the years ahead.

A sign of the pressing urgency of dreams come true is the attention now being paid to ways to record, store, retrieve, and analyze the mass quantities of data soon to be generated by the world's complement of interferometers. Talks among the various parties, most recently and intensively by LIGO and VIRGO, have led to the outlines of a specification for a common format to be used for recording data; at the TAMA workshop the Japanese scientists signaled their intention to aid in its design. This development was singled out by LIGO P.I. Barry Barish in his toast at the conference banquet, as a mark of the cooperative spirit that has marked this international endeavor and as a crucial step to ensure the linkage of interferometers into a worldwide observatory.

The foreign visitors enjoyed the chance to become better acquainted with the staff of the Japanese collaboration, especially with the students and other young scientist who carry so much of the burden in large projects such as this. A highlight of the meeting was the tour of the site of TAMA300, snugly ensconced underground on the attractive campus of the National Astronomical Observatory at Mitaka, in the Tokyo suburbs. All three buildings and their connecting 300 meter tunnels are complete, and large vacuum hardware is everywhere in evidence. In the vertex building, visitors had the chance to inspect the intriguing X-pendulum low frequency vibration isolation system, under the proud and watchful eye of designer Mark Barton. If the rest of the interferometer can be constructed as nicely as the parts completed to date, then successful attainment of the design sensitivity (rms strain of 3×10^{-21}) should be possible by the target date of 1999.

Thus, TAMA300 should inaugurate the large interferometer era of gravitational wave detection. If all goes according to plan, it will be joined on the air by GEO 600 (near Hannover) in 2000. VIRGO plans to complete the construction of its 3 km interferometer in Cascina (near Pisa) in 2001. LIGO will have completed construction of its two 4 km long interferometer sites in 1999, followed by a two year period of commissioning. By 2002, its three interferometers (one at Livingston, Louisiana and the 4 km / 2 km pair at Hanford, Washington) are expected to be on the air for an inaugural two year data run. In the meanwhile, the Japanese hope to begin work on a 3 km interferometer by 2000, filling out a network that truly spans the globe.

Midwest gravity meeting

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The sixth annual Midwest Relativity Conference was held at Bowling Green State University in Bowling Green, Ohio on Nov. 1-2, 1996. There were about 50 participants, most of whom gave talks. Each talk was 15 minutes long. For the most part the topics covered fell into the following categories: 1) Numerical Relativity, 2) Mathematical Relativity, 3) Observational Topics, 4) Quantum Gravity, and 5) Alternative Theories of Relativity.

Numerical Relativity. There were quite a few talks which utilize numerical techniques, but several were more or less devoted to issues which center on the numerical implementation of Einstein's theory in two and three spatial dimensions, with and without matter. Beverly Berger discussed evolutions of $U(1)$ symmetric cosmologies, showing the tracking of regions of large curvature using her $U(1)$ symmetric code. David Garfinkle talked about a new symplectic algorithm for the evolution of mixmaster spacetimes which accurately evolves to late times. Jorge Pullin gave an overview of the successful 'close approximation' for colliding black holes and discussed its salient features and applications. Serge Droz discussed a numerical investigation of black hole interiors. Keith Lockitch reported on his investigations of how to numerically construct a family of asymptotically flat initial data sets which are axisymmetric and geodesically complete as counter-examples to the cosmic censorship conjecture. Comer Duncan gave a talk about a new hyperbolic solver for vacuum axisymmetric spacetimes which combines the Geroch manifold of trajectories approach with a symmetric hyperbolic form of Einstein's equations, and discussed a numerical implementation and tests on weak gravitational waves. Mark Miller reported his investigations into the utility of Regge Calculus for numerical relativity, focussing on issues of consistency and stability. Grant Mathews discussed his work on the appearance of instabilities in close neutron star binaries.

Mathematical Relativity. There were a wide variety of topics in mathematical relativity. Ulrich Gerlach discussed some recent work on a variety of topics, including paired accelerated frames, diffractive scattering, and achronal spin. Jean Krisch reported on some work on string fluid stress energy. Steve Leonard talked about the appearance of tail effects for various types of fields in curved spacetimes. Ted Quinn reported his investigations into an axiomatic approach to electromagnetic and gravitational radiation reaction. Shyan-Ming Perng talked about his research on conserved quantities at spatial infinity. Ed Glass discussed the calculation of the Bondi mass from Taub numbers, while Jim Chan discussed radiative falloff in non-asymptotically flat spacetimes. Juan Perez-Mercader presented his views on how self-organized criticality may be expressed in the universe. Kevin Chan talked about modifications of the spinning BTZ black hole when the theory contains a dilaton field. Masafumi Seriu gave an overview of his work to characterize the global geometrical structure of a space in terms of the spectra of a suitable operator, including discussion of a measure of closeness of two universes based on the spectra. There were two talks utilizing torsion. Richard Hammond discussed gravitation with torsion derived as the exterior derivative of a second potential, built so that electromagnetism may be generalized such that the source of the torsion gives rise to the magnetic dipole moment of the electron. Harry Ringermacher gave a treatment in which gravity with torsion is present to encode the electromagnetic field and discussed several solutions.

Observational Topics. Mark Beilby gave a talk about methods of predicting test mass thermal noise by measurement of the anelastic aftereffect in the context of the LIGO project. Eric Poisson talked about the dual use of space-based interferometers to measure black hole parameters and as a means of testing general relativity. Andrew de Laix gave a treatment of the gravitational lensing signature of long cosmic strings. Bob Wald gave an overview of some recent work on galactic and smaller scale gravitational lensing, while Daniel Holz followed with further developments and some applications. Philip Hughes discussed some recent high resolution relativistic extra-galactic jet simulations as a possible probe of aspects of super-massive black holes.

Quantum Gravity. The variety of topics which are quantum related was quite wide in scope. Leonard Parker gave a talk about his research on 2D black holes, reporting on his work on the formation and evaporation of 2D black holes in dilatonic quantum gravity. Louis Witten talked about the formation and evaporation of naked singularities in 2D which suggest that the naked singularity will not exist but instead there would be a large outburst of radiation. Ivan Booth reported on the cosmological production of charged and rotating black hole pairs. James Geddes gave a discussion of some recent work on whether there exists a measure on the space of all paths in Schroedinger quantum mechanics such that the time evolution of the system is given by an appropriate path integral. He give an example of a system for which the answer is no. Hong Liu talked about quantum hair, instantons, and black hole thermodynamics. Bob Mann then gave a report on the pair production of topological anti de Sitter black holes. The talks by Michael Pfenning and Matt Visser were of a different orientation. Pfenning discussed quantum inequalities in static curved spacetimes. Visser gave an overview of the violation of energy conditions at order hbar, showing how the polarization of the vacuum by the semi-classical gravitational field causes a shift in the stress-energy which violates all the classical energy conditions. Rhett Herman talked about the use of the DeWitt-Schwinger point-splitting technique to construct the stress-energy of a complex scalar field in curved spacetime.

Alternative Theories of Relativity. Ken Seto discussed a special relativity alternative. Edward Schaefer talked about means of eliminating black holes from relativity theory.

The Sixth Midwest Relativity Conference included a wide variety of talks, giving ample evidence of the breadth of interests of relativists in and around the midwest. The meeting at Bowling Green demonstrated that the midwest meetings have achieved a stable status.

Thanks to all who attended! The next meeting will be at Washington U. in St. Louis with Wa Mo Suen the prime contact. See you all at the next meeting!

OMNI-1 Workshop

and the beginning of the International Gravitational Radiation Observatory

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The First International Workshop for an Omnidirectional Gravitational Radiation Observatory (OMNI-1) was held at São José dos Campos, Brazil, in May 23-30, 1996. It joined up some of the most active scientists now working in the field of gravitational wave detection, representing six countries[1] and the major experimental projects in the world[2]. The meeting allowed researchers and students to present the state of art of the projects and to exchange experiences among their groups. Also, during the opening talks and the six sections of OMNI-1 the participants had the opportunity to discuss about many important issues regarding gravitational wave research.

Several theorists contributed with interesting works on super-string theory, cosmic strings, gravitational emission and theoretical gravity. Also, talks on the emission of gravitational waves from supernovae, black-holes collisions, binary coalescence and radio pulsars were presented.

Experimentalists from both resonant-mass and interferometric projects talked about virtually all the most important aspects concerning gravitational wave experiments nowadays. For instance, the detectability of gravitational signals generated by the coalescence of binary systems, precessing neutron stars in the galaxy or core collapse events was discussed, as well as the influence of cosmic rays on resonant-mass detectors. And several results were shown concerning transducer construction techniques, thermal cooling methods and the research on special materials to be used in spherical antennas.

Scientists representing the different projects talked about the present status of their experiments and showed exciting new results that suggest that more progress is expected in this field of research for the next years. One of these breakthroughs is the construction of a fourth generation of resonant-mass detectors using large spherical antennas, which is under consideration by almost all the groups working with this kind of detectors.

The concluding session of the Workshop (the roundtable section) created an opportunity to increase the collaboration among the groups. It was clear for the participants that in the field of gravitational wave detection scientists are working at the edges of technology and science so that international collaboration becomes essential. Therefore they decided to formalize the OMEGA Collaboration[3],intended to create an International Gravitational Wave Observatory, composed by a network of resonant-mass (using both bars and spheres as antennas) and interferometric detectors , under coordinated operation. Such observatory is expected not only to detect gravitational wave signals, but also to determine their intensities and polarizations, as well as the directions of their astrophysical sources, in a large spectrum of frequencies.

[1] Australia, Brazil, Italy, The Netherlands, Russia and USA.

[2] LIGO, VIRGO, AIGO, NAUTILUS, ALLEGRO, AURIGA, ALTAIR, ELSA, GRAIL, PERTH and EINSTEIN.

[3] OMEGA homepage is on the WEB site http://phwave.phys.lsu.edu/omega/

The final result of the Workshop - the OMEGA Collaboration - represents a major effort of scientists working on gravitational wave detection from all around the world. Their intention is to join their capabilities, experiences, resources and ideas to create a revolutionary scientific tool and develop a new means to study the universe: Gravitational Astronomy.

Chandra symposium

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A Symposium on "Black Holes and Relativistic Stars" was held on the University of Chicago campus on the weekend of December 14 and 15, 1996. The Symposium was dedicated to the memory of S. Chandrasekhar, who died in August, 1995 and had devoted much of the last 30 years of his scientific career to research in these areas. Although the Symposium was originally envisioned as a relatively "small" meeting, it was attended by over 500 registered participants, about half of whom came from outside of Chicago. Many of the participants stayed to attend the "Texas Symposium", which was held in downtown Chicago during the following week. The Symposium consisted of twelve plenary talks, each one hour in length. Valeria Ferrari opened the Symposium on Saturday morning with a review of her work, done in collaboration with Chandrasekhar, on perturbations of black holes and relativistic stars. John Friedman reviewed work on rotating relativistic stars, including the information to be gained from millisecond pulsars on neutron star matter. Kip Thorne brought us up to date on the status of LIGO and VIRGO and reviewed what we might learn from them and LISA about black holes and neutron stars. In the Saturday afternoon session, Martin Rees reviewed the observational evidence for black holes, including some new, strong evidence for black holes at the centers of galaxies. Roger Penrose presented some perspectives on cosmic censorship and singularities. Saul Teukolsky described some of the ongoing research in numerical relativity, aimed at analyzing the collisions of black holes. In the Sunday morning session, Werner Israel discussed his work and that of others on the internal structure of black holes. I reviewed the status of black hole thermodynamics, with an emphasis on the apparent "universality" of the laws. Rafael Sorkin then presented some of his ideas related to the statistical origin of the laws of black hole thermodynamics. The Sunday afternoon session began with James Hartle describing generalized quantum theory and how it might treat issues associated with black hole evaporation. Stephen Hawking reviewed his ideas on the loss of quantum coherence due to black holes and briefly described a new calculation related to this process. The Symposium concluded with a relatively non-technical talk by Edward Witten, which reviewed the development of ideas in string theory and gave his present perspectives on "quantum and stringy geometry". The proceedings of the Symposium will be published by the University of Chicago Press, and should be available in early 1998.

Penn State Meeting

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On November 8-10, at University Park, the Fourth Annual Penn State Conference took place. This year's conference was titled "New voices in relativity and quantum gravity" and featured plenary speakers that were at the postdoctoral level in their careers. It also had short oral contributions in the afternoons which were allotted in a first-come, first-serve basis, much along the model of the Pacific Coast and Midwest meetings.

The plenary speakers were Greg Cook (Cornell), Simonetta Frittelli (Pittsburgh), Gabriela González (MIT-LIGO), Juan Maldacena (Rutgers), Hans-Peter Nollert (Penn State), Amanda Peet (Princeton), Thomas Thiemann (Harvard).

Between them they discussed new developments in gravitational physics, on both the quantum and classical side. González told us about the status of the construction of the LIGo detectors, while Cook and Nollert reviewed the status of calculations to model astrophysical events such as colliding black holes that may provide signals for LIGO. The important new developments in string theory, that have made it possible to compute the entropies of extermal and near extremal black holes were the subjects of the talks by Maldecena and Peet. Thomas Thiemann described his recent work in non-perturbative quantum gravity which results in the construction of at least one version of quantum general relativity, while Frittelli described the work of herself and her collaborators which leads to a reformulation of general relativity in terms of the dynamics of null surfaces.

There were also a large number (41!) of contributed talks, spanning most areas of interest in relativity.

Part of the idea of the meeting was to launch in the East a series of meetings of similar spirit to that of the Midwest and Pacific Coast meetings. The next such conference will be organized in Syracuse University next year.

Aspen Winter Conference on gravitational waves and their detection

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The 1997 Aspen Winter Conference on Gravitational Waves and their Detection (the third in this series) took place in Aspen, CO, January 26 to February 1st, 1997. It was originally planned to stress three main areas, Advanced Detector Research and Development, Collaboration Formation for Advanced Detectors, and the LIGO Research Community. By the time that the meeting finished, an air of excitement and exuberence prevailed. New and exciting ideas, both experimental and theoretical had been introduced, and a number of collaborative efforts had been organized. In addition, issues of a political and organizational nature were raised and discussed openly.

The meeting was held under the auspices of the Aspen Center for Physics. The morning sessions were held in the Flug Forum, a beautiful auditorium in the new building of the Physics Center. The evening sessions were held in the Conference Center of the Aspen Institute of Humanistic Studies. Most of the participants were comfortably housed in the nicely appointed apartments of the Institute. There were 61 participants, including representatives of all existing and planned interferometers and bars.

Reports on the status of Virgo, GEO 600, LIGO , ACIGA, TAMA 300, and Bar Detectors by Giazotto, Hough, Shoemaker, Munch, Barton and Hamilton framed the conference.

Because the time has come for serious discussion of how to best organize the physics effort that will operate and do research with LIGO, several sessions were devoted to gathering the views of the participants, working towards a consensus, and taking early steps in the formation of the requisite Collaboration. Discussions of how to initiate formation of the LIGO Collaboration started early in the Conference in a session on Monday night, following introductory remarks by Gary Sanders. These discussions continued throughout the Conference, both formally and informally. They were addressed in the LIGO Research Community formal session, where Dave Berley presented the NSF views of LIGO structure, management, and goals. A recapitulation of the discussions was given in the final session by Finn and Saulson.

With construction of the LIGO Observatories well underway, and following the recommendations of the NSF McDaniel Report, the 1997 Conference focused on Research and Development for the next generation of detectors. Imaginative ideas for advanced interferometry, suspensions and seismic isolation, lasers, and optics were presented and freely discussed in both formal presentations and in many informal meetings. The GEO, JILA, Stanford and Virgo groups participated actively in these discussions.

In a theoretical vein, Jim Wilson and Grant Mathews presented work on General Relativistic Numerical Hydrodynamics for Neutron Star Binaries which questions the utility of the templates which are currently being implemented for analyzing neutron star binaries. Naturally, this engendered much discussion, and was addressed in Alan Wiseman's presentation. Bruce Allen and Sam Finn engaged in a colloquy on how to analyze data, and the bar people described how they extract signals from their data.

Tuck Stebbins reported on a possible speeded up LISA system, to be launched in the year 2004, instead of in 2015, that uses NASA vehicles together with existing LISA technology.

Choptuik showed where the Grand Challenge stands in its final year of funding.

The conference concluded with summaries by Finn and Saulson. The general feeling was that communications had been greatly enhanced between groups with different agendas. This was especially so in the "neutral" location of beautiful Aspen. The formation of the LIGO collaboration has been greatly facilitated. One important outcome of the conference was the formation of two working groups, one on high power laser R&D, the other on suspensions and seismic isolation. Exciting new physics questions have been raised, and the imaginative proposals for detection techniques stimulated everyone.

As for the past two conferences, a volume of all of the transparencies shown at the conference will be distributed to each participant shortly after the conference.