MATTERS OF GRAVITY

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

Number 7 Spring 1996

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Editorial

This is the second issue of MOG as official newsletter of the APS topical group in gravitation. There have been some changes in the way MOG is distributed. We used to have an informal mailing list for hardcopies of the newsletter. That is being discontinued. From now on MOG is distributed in hardcopy form to members of the APS topical group. For those of you on the old mailing list who are not members we will send a reminder with this issue. Email distribution will continue as usual through the gr-qc preprint archive, open to everyone.

In this issue we incorporate an official gossip column "We hear that". I guess people will have to be careful about what they tell me at conference banquets. We welcome brief news about people of the community of interest to others.

Due to production problems, we could not include an article contributed by Sam Finn about the Ligo Research Community. It will come out in the gr-qc preprint archive.

As usual I wish to thank the correspondents and especially contributors who made this issue possible. In this issue we say farewell and thanks to Jim Hartle and welcome Raymond Laflamme as correspondent on quantum cosmology.

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/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 2-5 are also available in gr-qc). All issues are available as postscript or TeX files in the WWW http://vishnu.nirvana.phys.psu.edu

Or email me. Have fun.

Jorge Pullin

Correspondents

1. John Friedman and Kip Thorne: Relativistic Astrophysics,
2. Raymond Laflamme: Quantum Cosmology and Related Topics
3. Gary Horowitz: Interface with Mathematical High Energy Physics and String Theory
4. Richard Isaacson: News from NSF
5. Richard Matzner: Numerical Relativity
6. Abhay Ashtekar and Ted Newman: Mathematical Relativity
7. Bernie Schutz: News From Europe
8. Lee Smolin: Quantum Gravity
9. Cliff Will: Confrontation of Theory with Experiment
10. Peter Bender: Space Experiments
11. Riley Newman: Laboratory Experiments
12. Peter Michelson: Resonant Mass Gravitational Wave Detectors
13. Stan Whitcomb: LIGO Project

Report from the APS Topical Group in Gravitation

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- **Elections:**

The first item of news is the successful completion of our first election. The officers are

Chair: Beverly K. Berger

Chair-elect: Kip S. Thorne

Vice Chair: Abhay V. Ashtekar

Secretary/Treasurer: James A. Isenberg

Executive Committee Members-at-large: James M. Bardeen**, L. Samuel Finn*, Leonard E. Parker***, Frederick J. Raab***, David H. Shoemaker**, Robert M. Wald*

*The number of asterisks denotes the duration of the term in years.

Thanks to everyone who voted!

- **Meeting:**

The official meeting of the TGG will be held during the 1996 APS/AAPT Joint Meeting, 2-5 May 1996, in Indianapolis, IN. The program of TGG activities consists of hosting an invited session and jointly hosting two additional invited sessions, one with the Division of Astrophysics and one with the Topical Group in Precision Measurement and Fundamental Constants.

** TGG Invited session:*

Clifford Will, "Gravitational Waves and the Death-Dance of Compact Stellar Binaries"

Frederick Raab, "Progress Toward a Laser Interferometer Gravitational-Wave Observatory."

Ho Jung Paik , "Spheres – omni-directional multi-mode gravitational-wave antennas for next generation."

Matthew Choptuik , "Critical Phenomena in Gravitational Collapse"

** Invited session with the Division of Astrophysics:*

Peter Meszaros, "Neutron Star Models and Gamma Ray Bursts"

Dong Lai, "Neutron Star Binary Coalescence"

John Friedman, "General Relativistic Instabilities of Neutron Stars"

Charles Meegan, "Observations of Gamma Ray Bursts"

** Invited session with the Topical Group in Precision Measurement and Fundamental Constants:*

Francis Everitt, "From Cavendish to the Space Age: Some Thoughts on the History of Precision Measurement"

Riley Newman, "New Measurements of G"

James Faller, "Precision Measurements with Gravity"

Paul Worden, "Testing the Equivalence Principle in Space"

In addition to these invited sessions, TGG will hold its first business meeting to be followed by a meeting of the Ligo Research Community.

Additional information under "Meetings Information" from http://www.aps.org.

•Fellows

The TGG will be able to nominate at least one of its members to become a Fellow of the American Physical Society. The deadline for such nominations to be received by the TGG is 1 April 1996. The procedure for those who wish to nominate a member of the TGG for Fellowship follows: (1) Insure nominee is a member of the Society in good standing. (2) obtain signatures of two sponsors who are members of the Society in good standing. (3) Submit signed Nomination Form, Curriculum Vitae, Biographical Information, Supporting Letters prior to the above deadline to: Executive Officer, The American Physical Society, One Physics Ellipse, College Park, MD 20740-3844, ATTN: Fellowship Program (see http://www.aps.org/fellowship/fellinfo.html)

If you are reading this newsletter and have not yet joined the TGG, you can contact membership@aps.org or follow "Membership" at http://www.aps.org.

Don't forget to browse the TGG home page http://vishnu.nirvana.phys.psu.edu/tig

We hear that...

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• *Wai-Mo Suen* of Washington University in St. Louis received the 1995 Outstanding Young Researcher Award from the Overseas Chinese Physicists Association (OCPA). The award, which has been given since 1992, recognizes achievement by young ethnic Chinese researchers working in North America and Europe. The award honored his innovative and seminal work in the application of computers to solving Einstein's equations for highly dynamical situations involving black holes and gravitational waves, particularly his discovery (with Ed Seidel) of a formulation of an event-horizon boundary condition for numerical codes. He received a $1,000 check and a certificate during the "Physics Without Borders" session of last April's American Physical Society meeting in Washington. (Thanks to Cliff Will for information).

• *Abhay Ashtekar* of Penn State was elected an "Honorary Fellow" of the Indian Academy of Sciences. According to the by-laws: "This is an international honor awarded by the Academy for distinguished contributions to Science. Scientists from all countries are eligible. The total number of Honarary Fellows can not exceed sixty."

• *Kip Thorne* of Caltech is the winner of the 1996 Julius Edgar Lilienfeld Prize of the APS. The citation reads "For contributing significantly to the theoretical understanding of such topics as black holes, gravitational radiation and quantum nondemolition measurements; for advocating tirelessly the development of gravitational radiation detectors; and for conveying lucidly the excitement of these topics to professional and lay audiences alike." For more information see `http://www.aps.org/praw/96winers.html` (thanks to Beverly Berger for the information).

LIGO Project Status

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Construction continues to move forward rapidly at both LIGO sites (Hanford Washington and Livingson, Louisiana). The rough grading activities at the Louisiana site are underway, and in Washington a contract to begin the construction of the 8 kilometers of foundations which will support the beam tube has been awarded. Our Architect/Engineering contractor (Ralph M. Parsons Co.) has completed the preliminary design for the buildings and associated site development. Parsons is now coninuing with the final design effort, and the preparation of the bid packages for the construction contracts.

Significant milestones were also achieved on the other major elements of the LIGO facilities. A contract for the construction of the LIGO beam tubes (which connect the vertex and ends of the two arms) was signed with Chicago Bridge and Iron, the company that performed the successful demonstration test last year. They are preparing for full production of the LIGO beam tubes and plan to begin installation by fall of this year. The contact for the final design, fabrication and installation of the remainder of the vacuum system was signed with Process Systems International, and they have begun intensive design work. This design work is scheduled to be complete by summer and will be followed by fabrication of the hardware to be delivered to the sites.

LIGO helped to organize a second Aspen Winter Physics Conference on Gravitational Waves from January 15-21, 1996. In addition to the usual technical interchanges among the experimenters present from the various groups around the world, there was a special emphasis on data analysis and the intereraction between experiment and theory in the analysis of LIGO data. The conference was also the first meeting of the LIGO Research Community, an organization of people interested in LIGO science. Another meeting of the LIGO Research Community will take place at the May APS meeting in Indianapolis.

A major effort in LIGO has been to push forward the design of the LIGO detectors. After careful consideration, the LIGO Project has made a working decision to switch its baseline interferometer design to solid-state lasers operating in the near-infrared in place of Argon ion lasers operating in the green. The new lasers are expected to result in comparable sensitivity and higher reliability in the initial interferometers. This decision also defines a clear path for later improvements to the initial interferometers taking advantage of rapidly progressing solid-state laser technology, and will permit closer cooperation with other gravitational wave groups who have generally adopted solid state near-infrared lasers for their detectors.

In the R&D program, investigations of noise on the 40m interferometer at Caltech continued. The 40 m interferometer has been converted to an optically recombined system, and will be converted to a recycled configuration later this year. At MIT, the initial phase of research with a suspended interferometer to investigate optical sources of noise has been completed. This interferometer, initially configured as a simple Michelson to emphasize the study of optical sources of noise and to minimize the amount of time needed to debug other noise sources, has been fully characterized. The next step, that of adding a recycling mirror to increase the optical power incident on the beamsplitter, is underway.

Further information about LIGO can be obtained from our WWW home page at
`http://www.ligo.caltech.edu`

General Relativity Survives another Test

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The deflection of light was one of the first great successes of general relativity, and continues to be an important testing ground. The original method, whereby the deflection of optical starlight was detected by measuring the displacement of positions of stars observed during a total solar eclipse, was replaced during the late 1960's by the methods of radio astronomy, following Irwin Shapiro's suggestion [1] that this would ultimately yield higher accuracy. The idea was to apply the precision of radio interferometry in differential angular measurements to monitor changes in the relative angle between pairs of radio sources, usually quasars, as they pass by the Sun (in radio astronomy there is no need to wait for solar eclipses). Although as much as 10 percent of the total deflection could result from the refractive effect of the ionized solar corona on the radio waves, this could generally be accounted for by working at several frequencies (the coronal effect varies as f^{-2}, while the GR effect is frequency independent), or by not observing the radio sources too close to the Sun (the coronal electron density falls off rapidly with distance from the Sun).

Between 1968 and 1975, more than a dozen experiments of this kind were done, culminating in an accuracy of about 1.5 percent, in agreement with GR (see [2] for review and references). The measurements were taken up again in the 1980s, making use of advances in Very Long Baseline Interferometry (VLBI), in which the radio telescopes that comprise the interferometer are separated by transcontinental and intercontinental baselines. These advances were made possible in part by improvements in atomic timekeeping and time transfer, permitting accurate determinations of the phases of the radio signals at such widely separated telescopes.

One effort involved measuring the deflections of 74 radio sources distributed over the entire sky [3]. The motivation of this program was geodesy, not GR. The idea was to use the radio sources as benchmarks for precise angular measurements to monitor the rotation rate and axis of the Earth. Nevertheless, the intrinsic accuracies (tenths of a milliarcsecond [mas]) were such that the deflection of a radio source almost anywhere in the sky was measurable. The grazing deflection is 1750 mas; for a source 2.5 degrees from the sun (the closest source in the sample) the deflection is 184 mas; while for a source at 90° from the sun, the deflection is 4 mas. Almost 350,000 observations of these sources were made between 1980 and 1990 using a world-wide network of radio telescopes. Two-thirds of the observations were between 50° and 130° from the Sun. What you lose by having small deflections you gain by statistics, and the reported result for the overall coefficient of the deflection, $(1+\gamma)/2$, was 1.0001 ± 0.001 [3]. Here γ is the PPN parameter whose value is unity in GR (see [2] for a review of the PPN formalism).

Recently, results from the more classic method of measuring the deflection of a single pair of sources very close to the Sun were reported by Irwin Shapiro and collaborators [4].

Indeed, the sources were the same quasars, 3C273 and 3C279, used in many of the original measurements of the 60s and 70s. The pair pass by the Sun every October 8; 3C279 actually is occulted by the Sun. The VLBI observations used two antennas at the Owens Valley Observatory in California, and two at the Haystack Observatory in Massachusetts, and were actually made during the fall of 1987. The quasars were observed until the corrupting effects of the solar corona became too large, despite the use of 3 different radio frequencies for most of the observations, corresponding to a maximum deflection of about 250 mas. This was the closest to the Sun that such a quasar has been tracked to date. The result again favored GR, with $(1+\gamma)/2 = 0.9998 \pm 0.0008$.

What are the prospects for improvement? According to [4], combining improved observations of specific sources close to the sun with data from the VLBI surveys of many radio sources could lower the uncertainty severalfold. Another option is to use orbiting observatories with optical interferometers capable of microarcsecond precision. Although there have been a number of preliminary projects in the U.S. to design and build such observatories, NASA seems to have pulled the plug on them. A European project called Global Astrometric Interferometer for Astrophysics (GAIA) has been approved by the European Space Agency as a possible future mission for the period 2006 – 2016. Its stated goal is to observe 50 million stars with 20 microarcsecond accuracy and to measure the coefficient $(1+\gamma)/2$ to 10^{-6}.

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Macroscopic deviations from Hawking radiation?

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Most work in quantum gravity assumes that the results of the semiclassical theory will be reliable until Planck scales are probed. However, in a recent paper, Jacob Bekenstein and Venceslav Mukhanov shows that this is not always the case. This paper, "Spectroscopy of a quantum black hole"[1] develops earlier proposals of theirs [2,3] that a black hole be considered a discrete quantum system. Remarkably, they show that simple assumptions about the spectrum of black hole states lead to predictions about the spectrum of evaporating black holes which could immediately be checked, given an observation of radiation from a black hole of any mass.

The usual derivations of Hawking radiation lead to the prediction that any black hole will radiate with a perfect thermal spectrum, with a temperature inverse to the mass, M. (for a neutral non-rotating black hole.) A number of authors have speculated that quantum gravity may lead to corrections to this formula, of the order of M_{Planck}/M (see, for example [4,5]). These are, for example, conjectured to arise if the spacetime geometry is discrete at the Planck scale. What is intriguing and surprising about the calculation of Bekenstein and Mukhanov is that it shows that a particular assumption about discrete Planck scale structure leads to a deviation from Hawking's prediction for the spectrum of a black hole that is of order one, whatever the mass.

The main physical assumption of Bekenstein and Mukhanov[1,2,3] is that the area of the black hole horizon is quantized, so that

$$A = n\alpha l^2_{Planck}$$

where n is an integer and α is a dimensionless constant of order one. (Information theoretic reasoning favors $\alpha = 4\ln 2$.) Bekenstein first proposed that the area of black hole horizons should come in discrete units more than twenty years ago [2], long before recent suggestions that something like this (although with a different spectrum) might be a prediction of a certain kind of approach to quantum gravity. Recently, the interest in this kind of assumption has been increased by Jacobson's remarkable demonstration that the classical Einstein equations can be derived from statistical thermodynamics, given a set of assumptions that includes the postulate that the information enclosed in a boundary is proportional to its area in Planck units[6].

Given the relationship between area and mass, a direct result is that the mass spectrum of a spherical black hole is discrete,

$$M = \frac{1}{4}\sqrt{\frac{\alpha n}{\pi}} M_{Planck}.$$

When a black hole evaporates it must make transitions between these energy eigenstates. For this reason there is a discrete spectrum of emissions, with a minimal frequency given by

$$\omega_0 = \frac{\alpha}{16\pi}\frac{M^2_{Planck}}{\hbar}\frac{1}{2M} = \frac{\alpha}{16\pi}\frac{1}{2GM}$$

It is facinating to notice that the $\hbar$'s cancel so that the resulting maximal wavelength is proportional to, and on the order of, the Schwarzchild radius.

If the assumption of integral quantization of horizon area is right then the consequence is that the emmissions from a spherical black hole are concentrated in lines with integral multiples of the frequency ω_0. This will differ radically from the Hawking spectrum, given that the peak frequency of the thermal spectrum is very close to the minimal frequency. ($\omega_{peak} \approx 2.82/8\pi GM$ while with $\alpha = 4 \ln 2 \ \omega_0 \approx \ln 2/8\pi GM$.) This means that were radiation observed from any spherical black hole, no matter what the mass, we could immediately distinguish between Hawking's prediction from semiclassical methods and the consequences of the hypothesis of integral quantization of horizon area.

One may question several assumptions about this argument. First of all, black holes may rotate and absorb and emit charges. For example, as photons and gravitons carry away angular momentum, an evaporating black hole will decay to states with non-zero angular momentum. One may ask whether this will change the picture of discrete line radiation. This is readily checked, and one may conclude that the result will be a fine structure coming from black holes making transitions between discrete values of angular momentum as well as area. But, as long as the angular momentum is small compared to the irreducible mass squared (in units $c = G = 1$) the resulting broadinging of the lines in wavelength is small compared to ω_0^{-1} [2]. One can also investigate further the statistical properties of the radiation, which Bekenstein and Mukhanov do[1]. It would also be interesting to investigate whether different hypotheses about the quantization of the area, such as those that come from the loop representation, lead to different predictions about the spectra of quantum black holes.

Whatever the outcome of this, what is clear is that observations of radiation emmited by black holes at scales of their Schwarzchild radii may be sufficient to test hypotheses about the Planck scale. It has sometimes been said that a black hole serves as a kind of a microscope which enlarges the high frequency fluctuations near the horizon to much longer wavelength, which then emerge as the Hawking radiation. What Bekenstein and Mukhanov add is that what is brought into view is, first of all, any discrete structure associated with the horizon itself. As a result, the quantum structure of the geometry of the horizon at the Planck scale is directly observable in the radiation emmitted at wavelengths of the order of the Schwarzchild radius of the black hole.

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Toroidal Event Horizons and Topological Censorship

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Recent work in numerical relativity has led to the development of techniques for locating the event horizon of a numerically generated black hole spacetime[1,2,3]. The event horizon, technically defined as the boundary of the causal past of future null infinity, is a global object in time. However, it turns out that even in a numerical simulation of finite duration in time, one can quite accurately locate the event horizon surface, if it exists, in many interesting simulations. The basic idea is quite simple: although outgoing light rays just near the event horizon will diverge away from it going forward in time, if one integrates backwards in time these same photons will be attracted to it[2]. Thus if one knows approximately where the event horizon is at late times in a numerical simulation (for example by finding an apparent horizon), one can integrate backwards in time to find a very accurate determination of the location of the event horizon at earlier times. What is more, the horizon surface geometry can be studied, and the horizon generators themselves can be traced and their properties, including caustic structures, can be analyzed using this technique. These ideas of backward integration and horizon analysis are discussed in detail in [2,3].

Combined with recent developments in numerical evolution of dynamic black hole spacetimes, including distorted, rotating, and colliding black holes, these tools open the possibilities for quantitative studies of event horizons in very interesting spacetimes. For example, the event horizons for the collision of two black holes, for both vacuum and matter spacetimes, and for rotating black holes, has been studied in a series of papers by different groups[1,2,3,4,5]. The interesting results of [5] are concerned with numerical studies of rotating black holes, and are a recent example of a developing synergy between numerical and mathematical relativity that is providing new insights into general relativity.

In Ref. [5], Shapiro, Teukolsky, and Winicour investigated the collapse of rotating collisionless matter to form a black hole, using a numerical code developed at Cornell[6]. A particularly interesting result, first reported in [1], is that in some cases before the final Kerr black hole is formed, whose horizon has the topology of a 2-sphere, a topologically toroidal horizon forms, that then evoles into the expected 2-sphere. This was the first example of a toroidal event horizon.

This result was further analyzed in [5] with the following consideration in mind: There is a theorem due to Gannon[7] that says that given asymptotic flatness and the dominant energy condition, an event horizon of even a non-stationary black hole must be topologically either a 2-sphere or a torus. The numerical result of [3] is clearly consistent with this theorem. However, Friedman, Schleich, and Witt[8] showed that any two causal curves extending from past to future null infinity can be continuously deformed into each other, creating the idea of "topological censorship". Following up on this result, Jacobson and Venkataramani[9] suggested that a toroidal event horizon might violate topological censorship, since one might be able to thread the middle of the torus with a causal curve that could not deformed into a curve that stays "outside" the torus. Shapiro, Teukolsky and

Winicour investigated how the toroidal horizon discovered in [1] could be consistent with the topological censorship theorem of [8].

Aided by a simple flat space model of a toroidal event horizon, they argue that such a horizon should have a line of "crossovers", where new generators cross and join the horizon, all the way around the inside of the torus. This crossover line is spacelike. According to this model the torus, once formed from gravitational collapse, should close up along the spacelike crossover line faster than light, as it races to form a 2-sphere. They then study the actual event horizon structure of their collapsing, rotating collisionless matter simulation. Since at late times this system forms a Kerr black hole with a spherical topology, by tracing light rays backwards in time from the final trapped surface, they can find the location of the surface, and trace its null generators, back through the formation of the toroidal horizon. They find that indeed at earlier times, although the horizon has the topology of a torus, an inner ring of crossovers is found where photons leave the event horizon (going backward in time). They conclude that as this crossover is spacelike, and closes up to form a 2-sphere faster than the speed of light, no causal curve can "link through" the torus and escape back out to the exterior region of the spacetime. Therefore, they conclude, the numerical result is consistent with all known theorems governing these systems.

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Critical Behavior in Black Hole Collapse

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Spherically symmetric gravitational collapse of matter is a surprisingly rich subject. The recent interest in the field was inspired by the work of Choptuik [1] in which he studied the collapse of a massless scalar field. For very weak initial data, the field bounces away. For very strong initial data, the field collapses to form a black hole. By using a sophisticated adaptive mesh algorithm, Choptuik showed numerically that by tuning a one parameter family of initial data labeled by p, he could make an arbitrarily small black hole (up to computer precision). The precisely critical solution, $p = p_{\mathrm{crit}}$, which is in some sense a zero mass black hole, has a number of fascinating properties. First, the critical solution seems to be a universal attractor. All families of initial data approach the same critical solution at criticality. The critical solution is discretely self-similar (DSS), so all features are repeated at arbitrarily small scales. Finally, the mass away from criticality has the form $M_{\mathrm{bh}} = c_i(p - p_{\mathrm{crit}})^\gamma$, where $\gamma = 0.374$ is a critical exponent, again independent of the initial data.

Not long after [1], similar results were found numerically in the study of the axisymmetric collapse of gravitational radiation [2], and for the spherically symmetric collapse of a perfect radiation fluid [3]. These works did not have the numerical accuracy of [1]. They found different scales for the DSS solution, but the same critical exponent $\gamma \approx 0.36 - 0.37$. This led people to conjecture that γ was completely universal, independent of the type of matter.

Recent progress has been made in understanding the scalar field collapse. Because of self-similarity, the region near $r = t = 0$ contains arbitrarily high curvature in the precisely critical solution. A continuity argument based on Cosmic Censorship says that $r = t = 0$ should not be visible in finite proper time to an outside observer. Unfortunately, Choptuik's initial work was performed in $r - t$ coordinates, which break down when an event horizon forms. Hamadé and Stewart [4] looked at the scalar field collapse in double-null coordinates, which evades this problem. They showed that the region of high curvature is indeed visible in finite proper time to an outside observer. Shortly after [4] appeared, Stephen Hawking conceded his bet with Kip Thorne about the validity of the Cosmic Censorship Conjecture. Gundlach [5] and also [6] have studied the critical solution by assuming it is DSS and periodically identifying coordinates. The solution is still rather complicated.

As was first noticed in the collapse of a perfect radiation fluid [3], a great deal of simplification occurs in the critical solution when it becomes continuously self-similar (CSS) instead of DSS because Einstein's equations reduce to ordinary differential equations instead of PDE's. Analytical renormalization group arguments can be used to study perturbations of the critical solution [7], and the eigenvalue of the most unstable mode determines the critical exponent, with $\gamma = 0.3558$ for the radiation fluid [7]. This agrees with the results of numerical calculations, but it was not clear whether it is significantly different from the scalar field γ. Similar analytic calculations indicate that perfect fluids with different equations of state have different γ's [8], but no numerical work has been done to show that the CSS solution is actually the critical solution in those cases.

Another class of solutions which admit CSS solutions are various types of complex scalar fields coupled to gravity. The CSS solution for the standard complex scalar field was constructed in [9], and has a critical exponent $\gamma = 0.3871$ [10]. However, it was found analytically in [10] that the CSS solution is unstable, and they conjectured that the attractor is actually the DSS solution. This was confirmed numerically in [11]. Another type of complex scalar field is the axion/dilaton field found in string theory. The CSS solution for the axion/dilaton was constructed in [12]. We showed numerically in [11] that the CSS solution is indeed the critical solution for this matter, and found that numerical and renormalization group arguments agree that the critical exponent is $\gamma = 0.2641$. This was the first conclusive evidence that γ is not universal.

In summary, every type of matter studied has either a DSS or a CSS critical solution. These represent essentially zero mass black holes, and have singular points at the origin visible in finite proper time. Numerically, the mass scaling away from the critical solution has a matter dependent critical exponent γ, which we now have the tools to calculate analytically when the critical solution is CSS. Thus, studying the critical phenomena at the threshold for black hole formation has given us new insight about the strong field, nonlinear regime of General Relativity.

I haven't been able to mention all of the work in this field, such as the lower-dimensional studies or extremal black hole behavior. Problems for the future include relaxing spherical symmetry, including quantum effects such as Hawking radiation, and figuring out what type of matter is physically most important (colliding D-branes in M-theory?).

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Third Texas Workshop on 3D Numerical Relativity

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The third Texas Workshop on 3D Numerical Relativity was held in Austin, Texas from October 30 to November 1, 1995. The main goal of the meeting was to report and discuss progress within the Binary Black Holes (BBH) Grand Challenge Alliance. The workshop addressed five areas:

• *Computational Infrastructure:* Choptuik (Texas) reviewed the computational strategy of the Alliance. He pointed out that the existing and planned numerical codes are remarkably similar with respect to the basic data structure. The computational infrastructure of the Alliance is based on a Berger & Olinger adaptive mesh refinement approach (AMR). Two implementations of AMR with parallel capabilities are being considered: one is based on Fortran 90/HPF (Haupt/Syracuse) and the other, called Distributed Adaptive Grid Hierarchy (DAGH), written in C++ (Parashar & Browne/Texas). Choptuik emphasized that AMR is not a panacea for numerical relativity problems; proper unigrid construction is the key to success. Other talks addressed programming and problem solving environments, Web tools, I/O and visualization.

• *Hyperbolic Formulations:* Within the last year, it became apparent that Hyperbolic formulations of Einstein's field equations have the potential of providing a natural arena to implement apparent horizon boundary conditions and facilitate the extraction of radiation. An overview talk of hyperbolic reductions for Einstein's equations was given by Friedrich (Postdam) [1,2]. In general terms, depending on the starting point, there are two types of reduction formalisms: those based on the ADM equations and those whose starting point are the Bianchi identities. The BBH Alliance is currently considering two hyperbolic approaches in the development of numerical codes (Bona et al. [3] and Choquet-Bruhat & York [4]). Reviews of these approaches were presented by York (North Carolina) and Masso (NCSA). Both speakers stressed that a suitable hyperbolic formulation should allow for an arbitrary choice of shift vectors; furthermore, from the numerical point of view, it is convenient to be able to write the system as a flux conservative, first order, symmetric hyperbolic system.

• *3D Simulations:* There are three groups within the Alliance developing 3D black hole evolution codes: NCSA, Texas and Cornell. Seidel's (NCSA) presentation reported the progress in simulating distorted black holes and, in particular, the first 3D head-on collision of black holes. Suen (NCSA/Wash. U) addressed a critical aspect in the evolution of black hole spacetimes, namely inner boundary conditions when black hole singularities are excised from the computational domain. The Texas effort on evolution codes is based on the standard ADM equations. Correll (Texas) presented results from evolving Schwarzschild data in Novikov coordinates. Finally, the Cornell group presented the status of its 3D code based on Choquet-Bruhat & York hyperbolic formulation. The code is still under construction; however, preliminary results from evolving Schwarzschild data seem significantly promising. Baumgarte (Cornell) presented an interesting and useful approach to finite differencing complicated tensor equations, such as those present on the Choquet-Bruhat & York hyperbolic approach. This method takes advantage of Fortran 90 pointer aliases to produce "clean" codes.

• *Outer Boundary:* A series of talks addressed outer boundary conditions for the evolution codes and approaches to radiation extraction. The outer boundary infrastructure consists of three components: (1) identification of a world-tube along which data is extracted from the interior evolution, (2) exterior evolution and computation of the asymptotic waveforms, and (3) interpolation of data from the exterior evolution to the outer boundary of the interior evolution. For the exterior evolution, two approaches are currently under consideration: A perturbative method, which was reviewed by Abrahams (North Carolina) and a characteristic approach under the direction of Winicour (Pittsburgh). Bishop (South Africa) presented estimates of the computational efficiency of extraction and matching using the characteristic approach.

• *PPN and Perturbation Theory:* Finn (Northwestern) considered issues regarding the matching of binary black hole initial data with PPN calculations of the inspiral phase. An important aspect in the numerical simulation of black hole collisions is the physical interpretation of the initial data, in particular, its radiation content. At the final stages of coalescence, during the black hole ringdown, the work by Price and Pullin [5] has proven to work remarkably well [6]. Pullin (Penn State) presented current attempts to generalize this work to cases in which the perturbations are about initial data containing close black hole binaries.

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ICGC-95, Pune, India, Dec. 13-19

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This was the third 4-yearly meeting in the ICGC series and was held at the Inter-University Center for Astronomy and Astrophysics, which proved to be a magnificent place for such a gathering. In this short account I can only mention a few of the many interesting points from the talks and workshops.

The Organizing Committee, inspired by its Chairman, T. Padmanabhan, had chosen not to make this an all-purpose conference, but to concentrate on four themes: Cosmology, especially observations; Quantum Gravity; Gravitational Radiation; and Classical General Relativity.

The real universe, i.e. what we observe, was discussed in plenary lectures by Richard Ellis, Malcolm Longair and Jim Peebles. Ellis, speaking on lensing, showed that the Hubble Space Telescope gives us such good data on lensed images that we can in some cases tightly constrain the lens. It also allows us to investigate high-redshift galaxies without selection bias: there may already be evidence of flattening of the source counts. Current estimates of Ω from this data are in the range 0.4 to 0.6. He also said that recent observations of supernova of type 1A give $q_0 = 0.3 \pm 0.3$ give a good reason for thinking $\Lambda = 0$. Longair displayed HST data to show that the most active epoch of galaxy formation was at $z = 2-3$, around the maximum of the galaxy number evolution: there were some striking images of star-formation apparently triggered by radio jets. Peebles argued that various evidence suggests that galaxies trace mass, and that $\Omega \approx 0.2$. In a workshop, Rachel Somerville explained why the often-quoted figure of Davis and Peebles for galaxy velocity dispersion was an underestimate.

Turning to the imaginary universe, i.e. the theorists' models, George Ellis gave a number of recent important applications of classical GR in cosmology, such as the almost-EGS theorem, on the relation of almost-isotropy of the microwave background to the almost-isotropy of the universe, and the effect of focussing on inferred distances at the last scattering surface. Padmanabhan gave a nice review of nonlinear gravitational effects in structure formation, and Katz discussed the integral constraints, giving a nice derivation of the Traschen form from Lagrangian superpotentials.

In the workshops, Bagla noted that the orthodoxy of the 80s (inflation with cold dark matter, $\Omega = 1$ and $H_o \approx 50$) was now in trouble, which I regard as a very healthy development, it having for too long been the case that people (like me) who did not accept this view uncritically were simply ignored. Padmanabhan criticised another tendency in the field, namely that workers tend to ignore the results of large-scale structure calculations if they conflict with other arguments, rather than worrying about a genuine discrepancy: perhaps all those with an interest in cosmology should try making such calculations so they get an idea of the reliability. I also noted, in Sasaki's talk, the advent of inflation theories with low Ω. Longair and Peebles declared themselves "hard-line big-bangers", meaning they preferred to focus on the observational evidence rather on theoretically preferred values or models, and Longair in particular stressed that some of the parameters often quoted are based on very little data and that one should not rely on true values being inside 1σ error bars.

In quantum gravity, Halliwell gave an excellent talk on the interpretation of quantum theory based on the decoherence concept, Varadarajandescribed canonical quantization of dilatonic black holes, in work aimed at further understanding of the Hawking effect. Torre showed the internal time concept still has possibilities, and Pullin discussed some issues related to the new variables. I did not attend the quantum gravity workshops, but they will be reported in the forthcoming proceedings: they included papers on non-standard approaches, on semiclassical cosmology, and on quantum mechanics in non-inertial frames.

Shoemaker and Vinet gave us some insight into the subtleties of building the LIGO and VIRGO detectors, and the extreme care needed to reach high sensitivites and avoid noise sources. The planning and engineering involved are awe-inspiring: the facilities are intended for more than 20 years use. One-third of the total cost is in the vacuum tubes (including the concrete casing necessary to protect the tubes from the U.S. public's gun mania)! All scales, financial, spatial, temporal, accuracy, noise levels, were impressively large or small as appropriate. In the workshop Blair emphasized that bars will continue to be important: their sensitivities around 1 KHz will improve to remain comparable with first-generation LIGO, while an array of, say, 30 small bars could be a very effective instrument in the 4-7 kHz range looking for collapses of stars below 5 solar masses.

Sources were also considered, in plenary talks by Blanchet and Finn, which related to the very detailed calculations of wave generation, some of which were discussed in more detail in the workshop. There also, Blair noted the potential importance of a stochastic background from supernovae.

Classical relativity featured in Friedman's talk on topological censorship, though part of the argument rested on quantum theory, and Seidel gave a good talk on the present and future of numerical relativity. There was also an additional day devoted to celebration of 40 years since the publication of Raychaudhuri's paper containing his famous equation, and attended by Prof. Raychaudhuri himself, who gave some interesting background on its publication history and the reactions of referees. The speakers, on various aspects of singularities, collapse and black holes, were Brill, Clarke, Joshi and Szekeres. My own workshop talk set out some unsolved problems, while Senovilla reminded us that not all cosmologies were singular and Tavakol emphasized the importance of robust predictions if models were to be meaningful.

Seidel noted that there was scope for work on numerical relativity by small groups in association with the main centres. To me this emphasized the benefits to our community from the improved communications of which this newsletter is part, but those do not detract from the value of personal meetings, for which ICGC-95 proved an excllent opportunity: the organizers are to be congratulated.

The Josh Goldberg Symposium: Five Decades of Relativity at Syracuse

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A celebration marking Josh Goldberg's seventieth birthday was held on December 2, 1995 in the Physics Department at Syracuse University. Six speakers discussed various aspects of general relativity, quantum mechanics, and their intersection before a standing room only crowd of present, recent, not-so-recent, and honorary members of the SU Relativity Group. Attendees had assembled from as far away as Britain, Poland, and Indonesia.

Peter Bergmann, the founder of the Relativity Group at Syracuse and Josh Goldberg's original mentor, led off the morning session with a talk called "The Quest for Quantum Gravity". He reviewed the basic principles of the canonical quantization program. He explained that this program has occupied so much of the attention of the Syracuse group because it does not require the introduction of a background metric, and thus respects the spirit of general relativity. No idealogue, however, he concluded by emphasizing that all viable approaches to the problem of quantum gravity should be pursued, a view that he had held for over three decades.

Jim Anderson devoted his talk to the question "What is an Equation of Motion?", a subject to which Josh contributed substantially. Anderson's argument was that the Einstein-Infeld-Hoffman formalism is the only good approach in the context of general relativity, in spite of the fact that today the subject is considered obscure by many. Rather than providing a universal general-relativistic equation of motion, EIH gives a prescription for deriving approximate equations of motion tailored to different problems. Especially interesting to this reporter, an experimentalist, was Anderson's use of the method of multiple time scales to propose that time measures defined by 1) the dynamics of gravitationally bound systems, 2) electromagnetically-based clocks, and 3) the expansion of the Universe would each disagree with the other two, if they could be compared with sufficient precision.

The morning session concluded with a talk by David Robinson on the subject of "Lagrangians, Hamiltonians, and Einstein's Equations". His thoughts were motivated by a feeling of disappointment that, after 80 years, we have as yet no algorithmic way of solving Einstein's Equations, even for the vacuum case. Robinson believes that what is needed is a *geometric* reformulation of Einstein's equations. In the half flat case, the existence of a hyper-Kähler structure does this job. He expressed the view that the use of spin 3/2 fields might lead to a similar description of the full vacuum equations. He concluded by indicating several recent developments that suggest that a solution to the problem may in fact be close at hand.

Ted Newman's contribution, leading off the afternoon, was called "Light Cones and Quantum Gravity". In it he presented his work on re-expressing general relativity in terms of the geometry of null surfaces. This unorthodox point of view can also give a new point of view on linearized gravity. Newman's hopes for this approach come from the fact that it leads to a "fuzzy" description of space-time, even at the classical level. Perhaps this feature could be useful in the development of a full quantum theory of gravity.

Bob Geroch treated the attendees to "Three Tales of the Initial Value Formulation". He noted that the initial value problem is one of the central paradigms of physics, but that we nevertheless have an incomplete understanding of the circumstances under which it can be well posed. He illustrated this point with three disparate stories, described as a pair of mysteries plus one sitcom. He pointed out the difficulties in describing dust, an elastic solid, and gravity in a way that can satisfy the requirement that the equations of motion be symmetric and hyperbolic.

The final formal talk of the day was given by Abhay Ashtekar. Reporting on work that made up the thesis of his student Troy Schilling, Ashtekar described a novel view of "The Geometry of Quantum Mechanics." By comparing the mathematical structures of classical mechanics and quantum mechanics using the insights of the study of geometry, Ashtekar showed how one can recast quantum mechanics as a special case of classical mechanics. This geometric reformulation, although equivalent to the usual algebraic one, opens doors to non-linear generalizations of quantum mechanics. As Penrose has suggested such generalizations may play an essential role in quantum ravity.

After a pleasant dinner, the day was concluded by remarks from John Stachel. He placed Josh's career in the context of an apostolic succession, in which Peter Bergmann played the role of the rock upon whom Einstein founded his church of general relativity. Stachel underlined the great value of the clarity of reasoning and writing in Josh's early work, citing it as the single good way for those outside the inner circle of relativity to come to understand the progress that was being made. Many of the participants then rose to give testimony on the important role that Josh had played in their lives and careers. The laudatory mood was interrupted only by Ted Newman, who told a tale linking Josh to an international incident involving the attack on Pearl Harbor and the sinking of the Titanic, that can, we trust, be consigned to the apocrypha.

Relativity and scientific computing

A summer school in Bad Honnef, Germany, Sept. 18 – 22, 1995

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General Relativity is still regarded by many as something done with pencil and paper, leading to mathematically exact results which may, or may not, have physical meaning. However, computers have now become an important tool in general relativity as well. This summer school was devoted to giving young scientists and advanced students specializing in relativity a comprehensive overview over the use of computers in General Relativity.

The summer school was organized by the 'Gravitation and Relativity Theory' section of the German Physical Society (DPG), together with the German Astronomical Society (Astronomische Gesellschaft). It's main financial support came from the WE-Heraeus Foundation, with a contribution from the Graduate College 'Scientific Computing' Köln/St. Augustin. It took place in the physics center of the Deutsche Physikalische Gesellschaft, an impressive historical building surrounded by a small park, located in Bad Honnef, a town on the Rhine river just south of Bonn.

There are three main areas of computer application in GR: Numerical techniques for solving the field equations (and possibly matter equations), computer algebra, and visualization for results and diagnostics. Lectures on numerical applications included a review of the commonly used ADM (3+1) formalism, alternatives to this formalism, and standard numerical techniques used in this context. Computer algebra was covered by an overview over existing software, by in-depth lectures on specific packages, and by applications, such as solving partial differential equations. A general review of scientific visualization was provided, and specific aspects arising in connection with special and general relativity were discussed. In addition, relativistic visualization could be seen "in action" as a part of many other lectures as well.

Ed Seidel kicked off the lectures with an exciting review of the ADM (3+1) formalism and the conceptual as well as technical questions involved, such as slicing and gauge conditions, boundary conditions, initial data problem, extraction of graviational waves, or locating horizons. In his second lecture, he concentrated on results obtained by the Grand Challenge alliance, and by NCSA in particular, ranging from the evolution of a single black hole to the collision of two black holes in 3D to spacetimes including Brill waves.

David Hartley compared the characteristics of many available computer algebra tools. Details, such as whether expressions are evaluated immediately and/or recursively after the substitution of a variable, can make a considerable difference in a specfic case. A variety of examples provided some indication which system can be used for which type of problem. Hartley also delivered a lecture authored by **Eberhard Schrüfer**, who could not present it himself due to illness, on the differential geometry system EXCALC and its applications on relativistic physics and fiber bundles.

Making the invisible visible - this definition of visualization provided the guiding principle for the lectures by **David Kerlick**. He discussed the mathematical and technical basis of computer graphics, summarized available visualization techniques and environments, and demonstrated scientific applications. An evening show of visualization videos spanning a wide range of fields was very much appreciated by the audience.

Harald Soleng introduced the Mathematica packages CARTAN and MathTensor for tensor analysis. CARTAN is designed for tensor component calculations in Riemann-Cartan geometries, while MathTensor provides a framework for indicial tensor manipulations.

Carles Bona discussed the definition and the conditions for hyperbolicity of Einstein's evolution equations, and the relevance of flux-conservative systems in Numerical Relativity. He reviewed finite-difference numerrical methods and introduced Total-Variation-Diminishing methods for an improved treatment of steep gradients.

Thomas Wolf presented his symbolic program CRACK for solving partial differential equation. As examples, he demonstrated its use on the Killing equations and on the PDE system which determines infinitesimal symmetries of a 3rd order ODE that resulted in the course of solving Einstein's field equations.

Exotic smoothness and spacetime was the topic of **Carl Brans**. He convincingly demonstrated that the smoothness property even of topologycally trivial $\mathbf{R}^4$ are much more involved than many relativists might have thought before. While he did not show colored or animated visualization videos, he impressed the audience with the information that all calculations for his lecture had been done on his wristwatch, or rather on a cluster of 10^4 such watches.

Wednesday afternoon, a **hike** to a nearby village had been scheduled. Joachim Debrus, the center's administrator, provided us with a detailed coordinate system and warned us about various black holes we might encounter along the way. Nevertheless, the experiment showed that the combined expertise of so many theoretical relativists did not suffice to find the shortest path from the center to our destination. At least, nobody was captured by a black hole, so everybody eventually made it to the restaurant overlooking the Rhine river where coffee and cake was provided to revive our spirits after this exhausting adventure. A boat had been chartered to bring us back to Bad Honnef. It had about the size of a bathtub, but due to a favorable spacetime distortion everybody found room on board. Despite the sometimes rather daring route which our captain chose between the larger tourist boats and the many freight ships, we arrived safely in Bad Honnef.

Beverly Berger explained how cosmological singularities are investigated numerically, using symplectic integration to handle the constraints. She demonstrated the use of Mathematica to generate FORTRAN code for Einstein's equation form a spatially differenced variational principle, and presented animated videos to visualize her results.

Heinz Herold examined rotating and oscillating neutron stars, using a formulation equivalent to a minimum surface problem for the stationary, axially symmetric equilibrium state. He discussed the influence of the equation of state, central density, and angular velocity of the star. He also presented a new slicing condition for the ADM (3+1) formalism, based on the condition of constant mean extrinsic curvature, and compared this condition to the familiar maximal slicing and harmonic slicing conditions.

Scientific visualization in a relativistic context requires new concepts and techniques. **Hans-Peter Nollert** discussed ray-tracing algorithms for special and general relativity, and how they can be incorporated into 'conventional' ray-tracing software. The second lecture covered the visualization of two-dimensional surfaces by embedding them in three-dimensional Euclidean space, either solving a system of differential equations or constructing a wire frame representation.

A massive, self-gravitating complex scalar field can form a stable a boson star. **Franz Schunck** showed how the corresponding rotating configuration can be determined numerically, with regular energy density and Tolman mass.

Pablo Laguna discussed alternatives to the commonly used finite difference methods in Numerical Relativity, such as spectral methods and finite elements for solving the construction of initial data. In the second part of his lecture, he addressed the question of matter evolution in curved spacetimes, using particle-mesh techniques or smoothed particle hydrodynamics in curved space.

Anton van de Ven attacked the two-loop calculation for perturbative quantum gravity using FORM, a relatively new computer algebra program. He also gave a preliminary discussion of the feasibility of a three-loop computation in supergravity.

What happens at the center of our galaxy? **R. Genzel** concluded the school by presenting the fascinating detective's work that observers do to figure out what's going on. While the luminosity of the central few parsecs appears to be dominated by a cluster of hot starts, there is now firly compelling evidence for a central dark mass, consisting most likely of a million-solar-mass black hole.

Almost as important as the lectures were the informal discussions on physics and trivia conducted in the evenings (and nights) in the center's **wine cellar**. A good selection of German beer as well as German and French wines greatly facilitated these discussions. Some participants, accidentally grabbed the non-alcoholic beer variety, and were subsequently amazed at how much beer they could consume without feeling any adverse effects.

The proceedings of the school will be published by Springer in early 1996.

This year's school emphasized computer methods used in relativity. Next year, from August 19 – 23, 1996, a similar school, titled "Relativistic Astrophysics", will concentrate on the results of relativistic studies, in particular with respect to astrophysics.

Fifth Annual Midwest Relativity Conference

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The Fifth Annual Midwest Relativity Conference was held on Friday, November 10th and Saturday, November 11th at the University of Wisconsin–Milwaukee. Approximately seventy-five participants braved the cold, snowy weather to hear over fifty talks on a wide variety of topics, ranging from whether macroscopic traversable wormholes exist to the effect of the accretion disk gap on the maximum angular velocity of relativistic stars.

On Friday morning, Jorma Louko opened the conference with a talk on complex actions in two-dimensional topology change. This was followed by a series of talks by Leonard Parker, Yoav Peleg, and Sukanta Bose on black hole evaporation, unitary evolution, and the Hamiltonian thermodynamics of 2D dilatonic black holes. Eanna Flannagan and Steve Harris then described null spacetime singularities and the categoricity of casual boundary constructions, respectively.

Robert Mann, Kevin Chan, and Jolien Creighton reopened the discussion of black hole spacetimes by giving talks on the cosmological production of charged black hole pairs, the ADM mass for the GHS string black hole, and quasi-local thermodynamics of dilatonic black holes. Steve Winters-Hilt followed by describing the Hamiltonian thermodynamics of the Reissner-Nordstrom-anti-de-Sitter black hole, and John Friedman talked about spherically symmetric mini-superspace reductions. David Garfinkle and Comer Duncan closed the morning session with back-to-back talks on numerical investigations of Choptuik scaling in n dimensions.

The Friday afternoon session began with talks by Dieter Brill and Alan Steif on 2+1-dimensional multi-black hole geometries. Matt Visser and Thomas Roman then described Lorentzian wormholes and asked the question whether macroscopic traversable wormholes exist. Neil Cornish explained chaos and fractals in relativistic dynamics, and Tanmay Vachaspati talked about reproducing the standard model with charges replaced by magnetic monopoles. Gilad Lifschytz ended the first half of Friday afternoon session with a talk on black hole thermodynamics from quantum gravity.

The last session on Friday afternoon was devoted to topics involving numerical relativity. Paul Casper described a numerical simulation of black hole formation from collapsed cosmic string loops, while Mark Miller talked about the status of Regge calculus for numerical relativity calculations. Spectral methods for numerical relativity and for numerical investigations of cosmological singularities were the topics of talks by Lawrence Kidder and Beverly Berger. Nikolaos Stergioulas discussed the effect of the accretion disk gap on the maximum angular velocity of relativistic stars, and Steve Brandt and Karen Camarda described initial data for rotating black holes, and 3D numerical simulations of colliding black hole spacetimes.

Saturday morning began with talks on quantum field theory in curved spacetime. Robert

Wald described recent work on quantum field theory in spacetimes with compactly generated Cauchy horizons, including a general theorem that quantum fields have singular behavior at Cauchy horizons. Adam Helfer and Rhett Herman discussed the stress-energy operator and the renormalization of the charged scalar field, respectively. Theodore Quinn gave an axiomatic approach to radiation reaction in curved spacetimes, and Alpan Raval talked about a stochastic theory of accelerated quantum detectors. Gerald Graef described semi-classical fluid spheres, and Larry Ford told us about metric and light cone fluctuations in quantum gravity.

Asymptotic properties of spacetimes were also a topic of discussion, with Shyan-Ming Perng giving a definition of a new conserved quantity at spatial infinity, and Vivek Iyer describing a way of 'deriving' a Bondi mass for diffeomorphism invariant theories. Edward Glass followed with a talk about quasi-local mass, angular momentum, and the Penrose equation, and Elihu Lubkin described Lorentz transformations as seen in the planetarium sky. Russel Cosgrove and Richard Epp ended the morning session with talks on consistent evolution for different time slicings in quantum gravity, and the symplectic structure of GR in the (2,2) formulation.

The Saturday afternoon session began with two talks involving the cosmological constant. Steve Leonard started by making a case for a positive cosmological constant, while John Norbury described the quantum tunneling constraint on a decaying cosmological constant. Scott Koranda and Nicholas Phillips then gave talks on an absolute minimum for the rotational period of gravitationally bound stars with an equation of state constrained only by causality; and on texture cosmology and the cosmic microwave background. Jorge Pullin described the use of linearized theory to understand the head-on collision of two black holes, and Edward Schaefer proposed an interpretation of GR based on an alternative definition of the constancy of the speed of light.

The final session on Saturday afternoon was devoted primarily to experimental relativity and gravity wave experiments. Catalina Alvarez began with a talk on the equivalence principle and g-2 experiments. Eric Poisson then told us "the good news and bad news" of post-Newtonian approximations, while Liliana Simone and Alan Wiseman described the convergence properties of post-Newtonian expansions for gravitational waves, and the effect of equations of state on the inspiral of coalescing compact binaries. James Geddes discussed high energy cosmic rays, and Daniel Holz concluded the conference with a talk on line-emitting accretion disks surrounding Kerr black holes.

Finally, Comer Duncan volunteered to host the Sixth Annual Midwest Relativity Conference, to be held at Bowling Green State University sometime in November, 1996. Stayed tuned for more information.

Volga-7 '95

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In the year of the 85th anniversary of the birthday of Prof. A. Z. Petrov (1910-1972) a summer school dedicated to his memory was organized by the Chair of General Relativity and Gravity, which he founded in 1961 at Kazan State University. Held at Borovoye Matyushino (Kazan) from June 22 to July 2, 1995, it was the 7th International Summer School on recent problems in theoretical and mathematical physics. Sponsors were the Ministry of Science of the Russian Federation, the Russian Foundation for Basic Research, and the Government of Republic of Tatarstan.

The general purpose of this School is to create favourable conditions for involving young scientists and students in current scientific research, and to strengthen international scientific cooperation. The School's 71 participants came from 7 countries (Belgium, Czech Republic, Lebanon, The Netherlands, Russia, Ukraine, USA), and two thirds were young scientists, postdocs, or graduate students. The languages of the School were Russian and English, with Russian predominating. This presented an interesting challenge to the non-Russian-speaking participants and to the organizers. Fortunately at this conference each non-Russian-speaker could have his personal simultaneous translator. Some lecturers solved the language problem by speaking in Russian, but using overhead transparencies written in English. This was quite successful and is recommended for future conferences with two official languages.

Three topics were presented as main lecture courses:
Aspects of Analyticity (D. Brill, Maryland, USA)
Quantum Gravity (J. Buchbinder, Tomsk, Russia)
Elements of Mathematical Apparatus of Quantum Field Theory
(Ju. Soloviyev, Moscow, Russia)

In addition we were treated to a variety of 90-minute seminars:
A. Aminova (Kazan, Russia) — A. Z. Petrov as Scientist, Teacher and Scientific Leader
V. Bagrov (Tomsk, Russia), V. Belov (Moscow, Russia), A. Trifonov (Tomsk, Russia) — The Complex WKB Method
K. Bronnikov (Moscow, Russia) — Insular Configurations in Higher-Dimensional Gravity
K. Krasnov (Kiev, Ukraine) — Nonperturbative Quantum Gravity and Loop Expansion
M. Missarov (Kazan, Russia) — Exactly Solvable Fermion Hierarchical Models
S. Stepanov (Vladimir, Russia) — Irreducible Representations of the Orthogonal Group and a Geometric Theory of Gravity
M. Welling (Utrecht, Holland) — (2+1)-Dimensional Gravity
S. Chervon (Ul'yanovsk, Russia) — Chiral Nonlinear σ- Models and Cosmological Inflation
I. Tsyganok (Vladimir, Russia) — On Developable Vector Fields
J. Steyaert (Louvain-la-Neuve, Belgium) — On the Detection of Tachyons

These lectures and Seminars will be published in Russian and in English as Proceedings of the Summer School and will be available from the organizers (email enquiries to aminova@phys.ksu.ras.ru)

The name of the school recalls the magnificent river Volga that dominates the geography of the Kazan region, and indeed the School was held at a camp within a forest reserve on the banks of the Volga. Participants were housed in rustic A-frames and huts nestled among pine trees. A large geodesic dome provided conference space and dining facilities. After intensive discussions the fine weather invited recreation at the camp's volley- and basketball grounds, tennis courts, and beaches. There was plenty of opportunity for interaction in discussion as well as sports, and for typical Russian experiences such as the Sauna and the Tatar national competition "Sabantuy." Organized events and excursions included a visit of the City of Kazan and its Kremlin, a meeting with the next generation of physicists and mathematicians at the Summer School "Quant" for schoolchildren, a boat trip to the island Sviyazhsk (a notable 16th century architectural-religious memorial), a talent show, a banquet with numerous toasts and dancing, a concert by the University Chamber Orchestra conducted by Rustem Abyazov with the famous violinist Irina Bochkova (Moscow), and the traditional farewell bonfire on the bank of the Volga.