MATTERS OF GRAVITY

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Editorial

Peter R. Saulson, Syracuse University

Welcome to the debut issue of *Matters of Gravity*, a newsletter for the gravitational physics community of the United States.

Gravitational physicists are a rare and diverse lot. Spread around the country (and the world), we work mostly in small groups, with a great range of technical approaches to our work. We would probably benefit, both intellectually and politically, from a greater sense that we are, in fact, a community. (It was only this summer that the Physical Review recognized gravitational physics as a distinct area of study by modifying the subtitle of the D15 issue. Thanks to Jim Hartle for promoting this change.)

This newsletter is an attempt to help build that missing sense of community. It grew out of informal discussions between Abhay Ashtekar and a number of other attendees at the MG6 meeting in Kyoto last July. Our plan is to produce *Matters of Gravity* four times a year. I've agreed to serve as editor for the first year. Ashtekar will keep a hand in as associate editor, with special responsibility for theoretical gravitation.

As you can see in the rest of this issue, the central feature of the newsletter will be brief (one paragraph to one page) reports, summarizing new scientific results, research initiatives, or political events relevant to our work. We hope they will give a valuable overview of our diverse field.

To make sure our coverage is as comprehensive as possible, we've asked a number of you to serve as correspondents, each with responsibility for one part of the field. Some will write reports themselves, others will be contacting some of you to do the writing. The correspondents are listed below. If you see an important topic that is not being well-covered, or would like to volunteer your services as a correspondent, please contact the editor.

If you would like to submit a piece for the newsletter, you are welcome to do so. You may either contact the appropriate correspondent, or write directly to the editor. We accept submissions by e-mail, surface mail, or fax, at the addresses given below. Eventually we will produce a style manual for TEX submissions via e-mail, but for now any legible format will do.

This issue has been distributed in two forms. A paper edition, produced in TEX, was mailed to a list we derived mainly from the NSF's list of sponsored workers in gravitational physics. A larger number of you are receiving *Matters of Gravity* via e-mail. (Invaluable assistance in electronic circulation is being provided by Jorge Pullin.)

We hope that you will help us to reach people not on our initial list who would like to receive a copy. (Or, indeed, if you would prefer not to remain on our list, we will be pleased to strike your name.) Unless we hear otherwise, we'll continue to send you the newsletter in the form you first received it. A third format, e-mail distribution of a file with the TEX commands stripped out, will be made available if there is interest. Please send requests for inclusion in or deletion from our subscription list to the editor at one of the addresses listed below.

In future issues, we are considering also running announcements of upcoming meetings or perhaps listings of available positions. In addition, we would like your opinions on whether American gravitational physicists should form some sort of organization, perhaps a national section of the International Committee on General Relativity and Gravitation, or perhaps an independent group. As in the recent past, there may be times in the future when a quick and unified response from our community would be important. Whether you agree or not, we would be interested in your comments.

Please also send me your comments on this first issue of the newsletter, as well as suggestions for articles.

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Correspondents

1. John Friedman and Kip Thorne: Relativistic Astrophysics,
2. Jim Hartle: Quantum Cosmology and Related Topoics
3. Gary Horowitz: Interface with Mathematical High Energy Physics, including String Theory
4. Richard Isaacson: News from NSF
5. Richard Matzner: Numerical Relativity
6. 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. Robbie Vogt: LIGO Project
14. Francis Everitt: Gravity Probe-B

Experimental Notes

Clifford M. Will, Washington University

New constraints for Moffat's Nonsymmetric Gravitation Theory

Two recent papers have created problems for John Moffat's NGT. Gabriel *et al.* (*Phys. Rev. D*, submitted) have shown that the violation of the Einstein Equivalence Principle that is inherent in theories with a non-symmetric metric causes light with different polarizations to propagate differently in a gravitational field, and can lead to substantial depolarization of light from, say, a magnetically active region on the solar surface. Polarization measurements then place a strong constraint on the variable "l"-parameter of NGT. The other paper (Khaliullin *et al., Astrophys. J.* **375**, 314 1991) would seem to kick one of the legs out from under NGT. It explains the anomalously small inferred periastron advance of the binary system DI Her (which had been cited as evidence against general relativity and in favor of NGT) as being caused by a third, distant body. The effect is a combination of induced periastron shift, AND a periodic change in the orbital eccentricity of DI Her, which changes how one translates the observed eclipse times into a periastron advance.

A New Measurement of the Solar Gravitational Redshift

LoPresto *et al. (Astrophys. J.* **376**, 757, 1991) have reported a measurement of the gravitational redshift of chromospheric oxygen lines in the Sun, with a value 0.99 ± 0.02 of the prediction of the equivalence principle.

VLBI Leads to Improved Light Deflection Measurements

Using Very Long Baseline Interferometry, Robertson *et al. (Nature* **349**, 768, 1991) have reported measuring the deflection of radio waves by the Sun, in agreement with general relativity at the 0.1 percent level. The analysis used almost 350,000 observations of 74 radio sources, spread over the entire celestial sphere. They can now see curved space everywhere! Truehaft and Lowe (*Astronomical J.*, in press) have reported a VLBI measurement of the deflection of light caused by Jupiter (300 microarcseconds) at about 50 percent accuracy.

Orbital Decay of the Binary Pulsar Agrees with General Relativity

Observations of the binary pulsar during the summer of 1990 (J. Weisberg, private communication), together with a small correction to the observed rate of change of orbital period caused by galactic acceleration (Damour and Taylor, *Astrophys. J.* **366**, 501, 1991) now imply that the observed rate is 1.003 ± 0.008 of the general relativistic gravity-wave damping prediction. The new binary pulsar PSR 1534+12 (Wolszczan, *Nature* **350**, 688, 1991) may ultimately lead to even better accuracy.

Completeness of outgoing stellar modes

John L. Friedman, University of Wisconsin, Milwaukee

How can the outgoing modes of a star be complete in general relativity? For Newtonian stars, a superposition of normal modes describes an arbitrary perturbation of the fluid, but in relativity, one has both fluid and field degrees of freedom. Outgoing modes clearly cannot reproduce the incoming waves of an arbitrary radiation field. Worse, all outgoing modes of a stable star blow up exponentially at spatial infinity, and at first sight it appears that they cannot model any regular perturbation of a star.

Along a future light cone, however, one can specify smooth, finite-energy data for a normal mode, and it is possible to state two natural completeness conjectures. Remarkably, Viqar Husain and Richard Price [1] have just found a toy model of a relativistic star for which both conjectures can be made precise, for which both turn out to be true, and for which the proof is intuitively obvious. The conjectures are [see also 2]: (i) the normal modes are complete for initial data for the perturbed fluid at t=0, and (ii) the normal modes are complete in the space of purely outgoing solutions to the Einstein-perfect-fluid equations restricted to the causal future of the fluid at t=0.

The Husain-Price model of a relativistic star is a semi-infinite spring (they call it a torsion bar), extending in 1-dimension from $r = 0$ to $r = \infty$ (It is very close to a model considered earlier by Kokkotas and Schutz (1986) [3]). The spring has two parts, with different spring constants: A finite segment, the "star", extends from $r = 0$ to $r = L$ and has wave velocity v, the speed of "sound". The remaining infinite part, extends from $r = L$ to $r = \infty$ and on it waves have velocity c, the speed of "light". Because the wave operator with outgoing boundary conditions is not self-adjoint, one would not ordinarily know how to prove completeness of the normal modes. What saves the day is that for this particular system, every outgoing solution ϕ is damped with the *same* damping time τ and $\phi e^{it/\tau}$ is periodic. It is easy to see why this has to be true.

The general solution in the "star" is the sum of a right moving and a left moving wave, $\phi = \phi_R(x - vt) + \phi_L(x - vt)$. Now the left-moving wave, say, will reflect off the fixed origin, and after time L/v it return to its original position as a right moving wave with its sign changed. It then propagates to the right, part of the wave transmitted at $r = L$ and part reflected, with a reflection coefficient $e^{-T/\tau}$, that is independent of frequency. Finally after time $T = 2L/v$, it has returned to its initial position and velocity, with its amplitude changed by the factor $(-1)(e^{-t/\tau})$, as claimed. The right-moving wave, of course, performs the same reflections in reverse order. Thus $\phi = \phi_L + \phi_R$ has the property that $\phi e^{i(1+\pi)t/\tau}$ is periodic with period T.

Any function periodic in time with period $2L/v$ can be written as a superposition of modes with frequency $n\pi v/L$, and any outgoing solution ϕ can therefore be written as a sum of modes with complex frequencies. Thus conjecture (i) is true: The outgoing normal modes are complete in the space of solutions that are purely outgoing for $r > L$. Conjecture (ii) is the statement that the outgoing modes are complete for initial data on the segment $[0, L]$. This is also true, because arbitrary initial data on [0,L] gives rise to a unique outgoing solution on the spacetime.

Finally, an interesting result of Chandrasekhar and Ferrari [4] shows that, although the outgoing modes of a star may be complete for the fluid's initial data, they can carry information not contained in the fluid variables. In considering the outgoing modes of a dense spherical star, Chandrasekhar and Ferrari find an odd-parity outgoing mode. Because odd-parity perturbations do not couple to a spherical fluid, an odd-parity mode is unrelated to the fluid's degrees of freedom. Its character is closer to that of the outgoing modes of a black hole. Note that with a suitable definition of outgoing radiation, black hole normal modes may be similarly complete for the set of perturbations that are purely outgoing at infinity and ingoing at the horizon.

REFERENCES

[1] V. Husain and R.H. Price, "A model for the completeness of quasinormal modes of relativistic stellar oscillations." Submitted to *Phys. Rev. Letters.*

[2] J. L. Friedman, "Scenes from general-relativistic astrophysics," in *Recent Advances in General Relativity*, ed. A. Janis and J. Porter, Birkauer, in press.

[3] K. D. Kokkotas and B. F. Schutz, *Gen. Rel. Grav.* **18**, 913 (1986).

[4] S. Chandrasekhar and V. Ferrari, *Proc. Roy. Soc. A*, **434**, 449 (1991).

LIGO Project Report: October 1991

Rochus E. Vogt, Director, LIGO Project

The objective of the Laser Interferometer Gravitational Wave Observatory (LIGO) project is to establish a two-facility observatory to permit broadband observations (10 Hz to 10 kHz) of gravitational waves at strain sensitivities of $h \lesssim 10^{-23}$ for burst signals. This strain sensitivity may not be obtained with the initial detectors, but the facilities are designed to permit a sequence of detectors of higher performance to be developed and installed with minimal additional cost. The ultimate sensitivity has been set to ensure detection of coalescing neutron-star binaries (the most calculable source in terms of strength and frequency of occurrence), but earlier detection of less well understood sources (black-hole binary coalescence, black-hole formation, supernovae) is quite probable.

The project is being pursued, under NSF sponsorship, by a team of scientists and engineers from Caltech and MIT, with Caltech having fiduciary responsibility for the project. LIGO will ultimately be operated as a national facility open to the scientific community, offering opportunities for detector development and data analysis. At present, formal collaborations have been established with groups at Stanford University, the Joint Institute for Laboratory Astrophysics, and Syracuse University. LIGO will be part of an international network forming a global observatory.

After undergoing a number of peer reviews, LIGO was approved by the National Science Board in early 1990. Although proposed as a new start by President Bush for FY'91, Congress only approved funds for continued design and R&D. LIGO again is in the President's budget as a new start in FY'92, at a level of \$23.5M out of a 5-year construction total of $\sim$ \$211M. The House Appropriations action reduced LIGO funding for FY'92 to \$0.5M, while the subsequent Senate action allocated full funding of \$23.5M. On September 26, the Senate/House conference committee apparently approved full funding (\$23.5M) of LIGO for FY'92, and thus a construction start. We are awaiting further details and the President's signing of the final bill after the full Senate and House action.

Under a process approved by the National Science Board, the LIGO project opened a national competition for the two LIGO sites. Eighteen site candidates from 17 states have been offered, and now are undergoing technical evaluation. NSF action in the site selection process may occur by end of 1991.

R&D on LIGO detectors continues under a number of initiatives at both Caltech and MIT. Design of the first detectors to be installed in LIGO is underway. Large-scale demonstration projects, verifying LIGO design concepts and technology also are underway. These may be discussed in future contributions to this newsletter.

For anyone who would like to learn more about LIGO, a writeup of an MG6 paper: "The U.S. LIGO Project" (by R. Vogt) is available upon request to the LIGO Project office, Caltech, M/S 102-33, Pasadena, CA 91125, or by e-mail to information@ligo.caltech.edu.

Computational Relativity Grand Challenge

Richard Matzner, University of Texas at Austin

As a supplement to President Bush's Fiscal Year 1992 budget, the Office of Science and Technology produced a report: *Grand Challenges: High Performance Computing and Communication* (also known as the FCCSET report, since it was prepared by OST's Federal Coordinating Council for Science, Engineering and Technology.) This report proposes goals and strategies to bring the art of computing to the Tera operation/sec level, and networking to the 10-Gigabit/sec level by the year 2000. The strategy is to support hardware, network, and *software and algorithm* development, by involving different fields of numerical science in efforts that push the limits of current resources. Emphasis will be placed on projects that truly require the targetted computing power in order to succeed. Among the federal agencies charged with supporting this effort is the National Science Foundation, which funds a number of areas of computational physics.

Numerical Relativity is one of the most computationally demanding numerical sciences. A collaboration has been formed to propose a Grand Challenge effort in gravitational physics. The idea is to perform very high accuracy computations of the two-body problem in general relativity, and to predict the gravitational waveforms that result. At present, the collaboration members are the University of Illinois (National Center for Supercomputing Applications), Cornell University, the University of Pittsburgh, the University of Texas at Austin (Center for Relativity), Northwestern University, and the University of North Carolina at Chapel Hill.

We want to be able to solve generic problems without special symmetries, that is problems which are fully three-dimensional. The simplest such two-body problem is the two black hole case, since it removes all complications of astrophysics. And black holes, with the strongest possible gravitational fields, should be intrinsically strong and distinctive radiation sources.

About a dozen Ph.D.s, and a larger number of students, are already tackling different aspects of the problem. For instance, physically does it matter if we evolve matter to collapse to black holes which then collide, rather than taking "eternal" black holes which have no astrophysics and thus in some sense are simpler? Algorithmically is it better to take the ADM variables, or use the Ashtekar-variable formalism? Should one evolve the system by repeatedly computing space at "one instant of time"? Or would a null scheme be better, where one "time" is in fact a whole outgoing null cone, the entire history of radiation reaching infinity?

General Relativity allows wide latitude in coordinate choices. Which are better? Curvilinear coordinates can better snuggle up to the curved hole. But they tend to have difficult "coordinate singularity" behavior, and special points which require special coding attention. Rectangular coordinates have no special points, and are easy to code in, but don't conform very well to the structure of the problem. Many other such questions must be considered. In some cases the solutions may be straightforward, but careful attention must be given to each of these questions.

Estimates of the accuracy needed to evolve colliding black holes accurately to produce radiation suggest zoning sizes like $(1000)^3$ spatial zones, evolved at least 1000 steps into the future. Based on existing codes which take about 2×10^{-5} seconds per timestep on Cray Y-MP computers, this leads to years per simulation. (A Y-MP is capable of 2×10^8 floating point computations per second.) Parallelism is an obvious direction of improvement. The expectation is that well before the year 2000, parallel computers now being designed will achieve 10^{12} floating point operations per second, bringing the time scale for such a computation to the level of hours.

In the process of developing the general relativity codes, we will have tested and applied a wide range of numerical algorithms, and provided an education in computational science to many graduate and undergraduate students. We will also have produced a substantial library of community computer codes. And we will have predicted the signals in the new generation of gravitational wave detectors, which should allow us to probe to the edge of the universe.

Recent NSF Support for Gravitational Physics

Richard Isaacson, National Science Foundation

Present and recent NSF support for gravitational physics is summarized in the two tables given below.

HUMAN RESOURCES

		FY87	FY88	FY89	FY90	FY91
I. THEORY						
A.	**Analytic**					
1.	Faculty	49	41	47	49	45
2.	Postdoc	18	18	17	17	17
3.	Grad. Students	17	18	18	15	15
4.	Undergraduates	—	—	1	1	1
B.	**Computational**					
1.	Faculty	7	6	7	10	10
2.	Postdoc	3	3	3	6	8
3.	Grad. Students	5	7	6	6	10
4.	Undergraduates	—	—	1	2	1
C.	**Overall**					
1.	Faculty	56	47	54	59	55
2.	Postdoc	21	21	20	23	25
3.	Grad. Students	22	25	24	21	25
4.	Undergraduates	—	—	2	3	2
II. EXPERIMENT						
1.	Faculty	21	22	22	23	21
2.	Postdoc	9	9	7	11	13
3.	Grad. Students	19	21	25	25	24
4.	Undergraduates	—	—	15	16	14
III. LIGO (Caltech/MIT, Stanford, Colorado, Syracuse)						
1.	Faculty	3	3	6	7	10
2.	Postdoc	11	11	10	8	11
3.	Grad. Students	8	9	7	11	14
4.	Undergraduates	—	—	6	10	10

GRAVITATIONAL PHYSICS

SUPPORT LEVELS

AWARD SIZE (ANNUAL RATE): $ K/faculty

		FY87	FY88	FY89	FY90	FY91
I.	**THEORY**					
A.	**Analytic**	50.1	54.2	54.6	53.3	58.3
B.	**Computational**	69.5	83.7	71.2	66.8	80.4
C.	**Overall**	52.6	57.9	56.7	55.5	62.3
II.	**EXPERIMENT**	112.0	114.8	121.7	116.2	124.5
III.	**LIGO**	1065.6	1199.8	669.1	598.5	516.8

TOTAL FUNDING (ANNUAL RATE) : $ K

		FY87	FY88	FY89	FY90	FY91
I.	**THEORY**					
A.	**Analytic**	2407.0	2220.3	2565.5	2609.5	2623.7
B.	**Computational**	486.3	501.9	498.3	667.6	803.8
C.	**Overall**	2893.3	2722.2	3063.8	3277.1	3427.5
II.	**EXPERIMENT**	2542.2	2525.6	2677.8	2673.3	2614.6
III.	**LIGO**	3196.7	3599.3	4014.6	4189.8	5168.0
IV.	**TOTAL**	8632.2	8847.1	9756.2	10140.2	11210.1

COMPOUND GROWTH RATES

	$(FY91/FY87)^{1/4}$
I. **THEORY**	1.043
II. **EXPERIMENT**	1.007
III. **LIGO**	1.128
IV. **TOTAL**	1.068