MATTERS OF GRAVITY

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

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Editor

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Editorial

I just wanted to renew the invitation to everyone to suggest articles for the newsletter. The only way to keep the newsletter vibrant and balanced is if I hear from you, don't hesitate to email me with suggestions.

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

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

Jorge Pullin

Editorial policy:

The newsletter publishes articles in three broad categories,

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

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

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

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

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 We also do not publish full conference or meeting announcements, although we might consider publishing a brief notice with indication of a web page or other contact information.

Correspondents

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

Topical group news

Jim Isenberg, TGG secretary, University of Oregon
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• Election News

The ballot for this year's election is complete, and it will very soon be going out to all members. The list of candidates is as follows:

Vice Chair: Richard Matzner, Bob Wald.

Secretary/Treasurer: David Garfinkle, Ted Jacobson.

Delegate (Slot 1) John Friedman, Jennie Traschen.

Delegate (Slot 2) Matt Choptuik, Ed Seidel.

PLEASE VOTE.

• Annual Meeting

This year our annual meeting will be earlier than usual. It will be in conjunction with the APS Centennial Meeting, 20-26 March, 1999, in Atlanta, Georgia. This meeting is going to be very big. There will be a lot of bicentennial stuff (exhibits, lectures, historical talks), and it should be quite nice. Please check the web site: http://www.aps.org/centennial

The activities tied in with GR and gravitation include the following

Centennial Symposium: Einstein's Legacy: Nature's Experiments in Gravitational Physics (Tuesday, 24 March)

Clifford Will: Einstein's Relativity Put to Nature's Test: A Centennial Perspective

Robert Kirshner: Was the Cosmological Constant Einstein's Greatest Mistake?

David Spergel: The Cosmic Microwave Background: A Bridge to the Early Universe

Kip Thorne: A New Window on the Universe: The Search for Gravitational Waves

Invited Session: Progress in the theory of gravitation (Thursday, 26 March)

Robert Wald: Classical general relativity

Saul Teukolsky: Numerical methods

Gary Horowitz: Quantum gravity

Invited Session: Instrumentation for Gravitational Radiation Detection (Monday, 23 March)

David Shoemaker: Interferometric Detectors - overview

Peter Fritschel: Gravitational wave interferometer configurations

Jordan Camp: Requirements and performance of optics for gravitational wave interferometry

Eric Gustafson: Lasers for Gravitational wave interferometry

Peter Saulson: Thermal noise in gravitational wave interferometers

There will also be a number of focus sessions with invited and contributed talks (See www site), plus the Annual TGG Business Meeting, which will be on Wednesday at 5:30. PLEASE COME.

- Travel Support for the Annual Meeting

Last year, we decided that a useful way to spend our accumulating treasure is to support young people coming to the annual meeting. So this year, we will begin a program of small grants to help pay travel and/or lodging for the meeting in Atlanta. The people eligible for these grants are students and post docs. If you wish to apply, please send the following to Jim Isenberg (jim@newton.uoregon.edu).

1) A brief CV

2) A list of your publications

3) A supporting letter from a faculty member research group director

4) A tentative travel plan (including rough cost) for going to the meeting

The applications should be in by the 20th of February.

We hear that...

Jorge Pullin, Editor
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Stephen Hawking has received the Lilienthal prize from APS "For boldness and creativity in gravitational physics, best illustrated by the prediction that black holes should emit black body radiation and evaporate, and for the special gift of making abstract ideas accessible and exciting to experts, generalists, and the public alike."

Luis Lehner has received the Metropolis award from APS "For developing a method that significantly advances the capability for modeling gravitational radiation by making possible the stable numerical solution of Einstein's equation near moving black holes."

Beverly Berger was elected fellow of the APS "For her pioneering contributions to global issues in classical general relativity, particularly the analysis of the nature of cosmological singularities, and for founding the Topical Group on Gravitation of the APS."

Joan Centrella was elected fellow of the APS " For her original contributions to numerical relativity, cosmology, and astrophysics, in particular for her studies of large-scale structure in the universe and sources of gravitational radiation."

Ron Drever was elected fellow of the APS "For his fundamental experiment to test the isotropy of space, and for his pioneering contributions to laser interferometry as a tool for gravitational-wave detection."

Bernie Schutz was elected fellow of the APS "For his pioneering work in the theory of gravitational radiation, for the discovery of new instabilities in rotating, relativistic stars, and for elucidating how gravitational-wave observations can reveal astrophysical and cosmological information."

Stu Shapiro was elected fellow of the APS "For his broad contributions to theoretical astrophysics and general relativity, including the physics of black holes, neutron stars, and large N-body dynamical systems, and his pioneering use of supercomputers to explore these areas. "

Our warmest congratulations to them all!

The Chandra Satellite

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Those of you who knew Chandra and those who only knew of him will be pleased to learn that NASA has named its soon-to-be-launched Advanced X-ray Astrophysics Facility (formerly AXAF) the Chandra X-ray Observatory. The Chandra Observatory will join the Hubble Space Telescope and the Compton Gamma-ray Observatory in NASA's program of major space-based astronomical facilities. The final observatory in the series, for infrared astronomy (SIRTF), is under development.

The X-ray telescope in the Observatory has a larger collecting area (400 cm^2 at 1 KeV) and significantly better angular resolution ($.5''$) than previous X-ray telescopes such as those on the Einstein and Rosat observatories. Instruments include a CCD Imaging Spectrometer, developed by Penn State and MIT, and a High Resolution Camera, built by the Smithsonian Astrophysical Observatory. After Space Shuttle deployment, rockets will boost the Chandra Observatory into an unusual elliptical orbit with apogee more than 1/3 the distance to the moon. This will allow it to spend most of its time above the earth's radiation belts. The Chandra X-ray Observatory Center (CXC), operated by SAO, will control science and flight operations of the Observatory. Excerpts from the NASA press release are given below. For more information see the Chandra Observatory Web Site at http://xrtpub.harvard.edu/pub.html.

NASA's Advanced X-ray Astrophysics Facility has been renamed the Chandra X-ray Observatory in honor of the late Indian-American Nobel laureate, Subrahmanyan Chandrasekhar. The telescope is scheduled to be launched no earlier than April 8, 1999 aboard the Space Shuttle Columbia mission STS-93, commanded by astronaut Eileen Collins.

Chandrasekhar, known to the world as Chandra, which means "moon" or "luminous" in Sanskrit, was a popular entry in a recent NASA contest to name the spacecraft. The contest drew more than six thousand entries from fifty states and sixty-one countries. The co-winners were a tenth grade student in Laclede, Idaho, and a high school teacher in Camarillo, CA.

"Chandra is a highly appropriate name," said Harvey Tananbaum, Director of the CXC. "Throughout his life Chandra worked tirelessly and with great precision to further our understanding of the universe. These same qualities characterize the many individuals who have devoted much of their careers to building this premier x-ray observatory."

"Chandra probably thought longer and deeper about our universe than anyone since Einstein," said Martin Rees, Great Britain's Astronomer Royal.

"Chandrasekhar made fundamental contributions to the theory of black holes and other phenomena that the Chandra X-ray Observatory will study. His life and work exemplify the excellence that we can hope to achieve with this great observatory," said NASA Administrator Dan Goldin.

Widely regarded as one of the foremost astrophysicists of the 20th century, Chandrasekhar won the Nobel Prize in 1983 for his theoretical studies of physical processes important to the structure and evolution of stars. He and his wife immigrated from India to the U.S. in 1935. Chandrasekhar served on the faculty of the University of Chicago until his death in 1995.

The Chandra X-ray Observatory will help astronomers worldwide better understand the structure and evolution of the universe by studying powerful sources of X rays such as exploding stars, matter falling into black holes and other exotic celestial objects. X-radiation is an invisible form of light produced by multi-million degree gas. Chandra will provide x-ray images that are fifty times more detailed than previous missions. At more than 45 feet in length and weighing more than five tons, it will be one of the largest objects ever placed in Earth orbit by the Space Shuttle.

Analytical event horizons of merging black holes

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Probably all of us are familiar with the celebrated picture of the pair of pants that made it to the cover of the November issue of *Science* of 1995 [1]. This is the article where the geometry of the collision of two black holes is explained in rather lay terms (which has a definite appeal) and where an embedded picture of the event horizon of such a collision was generated by numerically integrating the light rays that generate the horizon.

But since I wish to make a point, it wouldn't be wise for me to leave up to the reader to retrieve his own copy of the journal because, if your desk is like mine, your copy must be buried beneath one of those stacks of paper. Or, unfortunately enough, it could even have been filed so ingeniously that you are sure now not to be able to find it. Let me instead save you the trip to the library; to start with, let me just borrow from the article the main features of event horizons: (*i*) The horizon is generated by null rays that continue indefinitely into the future. (*ii*) The null generators may either continue indefinitely into the past, or meet other generators at points that are thereby considered as their starting points. (*iii*) The cross-sectional area of the horizon increases monotonically to a constant at late times. We might as well say that the event horizon is a null hypersurface that does not self-intersect, which is formed by following each null geodesic in a bundle of finite area into the past just so far up to the point where it meets another geodesic of the bundle. In fact, if we have an expanding null hypersurface of finite area at late times, which generically does self-intersect in the past, we might as well regard as an event horizon the piece of the null hypersurface that lies to the future of the crossovers, and regard the crossovers as the boundary of the horizon.

In this context the "seam" along the inside of the trouser legs is a crossover line where the generators are terminated. The computer simulation [2] of the horizon provided deep insight into the nature of this boundary of the event horizon, distinguishing the caustic points (where neighboring rays meet) from the simple crossover points (where distant rays intersect without focusing).

The news is that *another* pair of pants has recently been released. It looks pretty much like the original, up to smooth deformations. My point is, however, that this newest pair of pants is not the product of numerical integration, but is the embedded picture of an analytical event horizon. There is now an analytical expression for the intrinsic metric of the event horizon of merging eternal black holes.

The new pair of pants was constructed by Luis Lehner, Nigel Bishop, Roberto Gómez, Béla Szilágyi and Jeff Winicour [3], of the University of Pittsburgh relativity group, which has traditionally sustained an interest in null hypersurfaces (tell me about it). The recipe for making this event horizon calls for all sorts of ingredients available in the pantry of the characteristic formulation of the Einstein equations. Surprisingly, perhaps, it does not call for a spacetime metric. Surprisingly, because one might think that, since the metric is needed in order to find geodesics, the horizon could only be known *a posteriory* of finding the spacetime metric.

The key to this remarkable work is to understand that the event horizon can be used as partial data for constructing the spacetime metric. From this point of view, the metric will be known *a posteriori* of finding the horizon! And the horizon is found by solving only constraint equations, namely, equations interior to the horizon itself.

More precisely, the horizon is regarded as one of two intersecting null hypersurfaces that jointly act as the initial surface for evolution in double null coordinates. In this case, the conformal metric of the null slice constitutes free data. The authors choose the conformal structure so that the 3-metric of the horizon is $\gamma_{ij} = \Omega^2 h_{ij}$ where h_{ij} is the pullback of the Minkowski metric to a self-intersecting hypersurface which is null with respect to the Minkowski metric. (An example of such a self-intersecting hypersurface is the hypersurface traced in four dimensions by the imploding wavefront of an ellipsoid in 3-space.) The conformal factor is then determined by the projection $n^a n^b R_{ab} = 0$ of the vacuum Einstein equations along the null generators n^a of the hypersurface. This is an *ordinary* second-order differential equation for Ω that determines the dependence of Ω on the affine parameter u along one null geodesic. Apparently, finding the solution is quite simple. The freedom is huge, but the authors point out that Ω^2 relates to the cross-sectional area of the light beam, and thus its asymptotic behavior is fixed by the condition that the area must be finite at late times $u \to \infty$. Furthermore, the behavior of the area element at the boundary of the horizon is determined by the property of the boundary of containing either caustic points or plain crossovers, which is also used in restricting the behavior of Ω^2. The requirement that the Weyl curvature must be regular provides further tips for the integration. The intrinsic geometry γ_{ij} of the horizon is thus found explicitly in terms of two angular coordinates (θ, ϕ) labeling the light rays, and the affine parameter u, acting as a time.

It is rather instructive to see how the figure arises. The pair of pants is constructed by stacking up 3-dimensional Euclidean embeddings of 2-dimensional surfaces obtained by slicing the horizon with constant-u hypersurfaces. Actually, the figure corresponds to a case of symmetry of revolution, so that one dimension can be ignored, but this is exactly as in the case of the "computational" pair of trousers of the *Science* article. Also, strictly speaking, the calculation represents the fission of two white holes, but time reversion allows for its interpretation in terms of the merger of two black holes. At no time does the conformal geometry used as data exhibit more than one hole. However, the horizon obtained by integrating the single Einstein equation does have two holes at early affine times, and just one hole at late affine times. The authors attribute these interesting features to the richness of the Einstein equations; still, a good deal of foresight on their part must have helped bring them to light.

References:

[1] R. A. Matzner, H. E. Seidel, S. L. Shapiro, L. Smarr, W.-M. Suen, S. A. Teukolski and J. Winicour, Geometry of a Black Hole Collision, *Science* **270**, pp 941-947 (1995).

[2] Please check the *Science* article for references to several authors that contributed computational results collected in the article.

[3] L. Lehner, N. T. Bishop, R. Gómez, B. Szilágyi and J. Winicour, Exact Solutions for the Intrinsic Geometry of Black Hole Collisions, gr-qc/9809034

LIGO project update

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LIGO Installation is once again the focus of our efforts in the LIGO Lab. Because the activities are so hands-on, this Update is mostly in graphical form with the text serving as captions for the photographs which can be found at ftp://ligo.ligo.caltech.edu/pub/mog/figures29jan98.pdf

We start (Fig. 1) with a view from space of the Livingston Observatory. The 4km arms are visible (as the clearing of the forest), and in the detailed view the 'X' shaped main building can be made out. Descending from angel to airplane height, we now see clearly the high-bay space containing the interferometer components on the right, the covered beam tubes in the background and to the right, and the entrance and offices in the right foreground. (The 'overpass' and the black water tank are fire precautions.)

A view inside the high bay (Fig 3), this time from Hanford, shows a number of the test-mass vacuum equipment chambers (the taller vertical cylinders), some 'HAM' multipurpose chambers (the two to the right), the main beam tubes (the large horizontal tubes to the far left and the right background), and a few of the many electronics racks. Navigating around the equipment involves lots of walking and climbing of stairs!

Several 2km sections of the beam tube (Fig 4) have been successfully 'baked out'—heated to drive off excess water and other contaminants. We see here a section of beam tube, wrapped in insulation, a heavy cable snaking across the floor to deliver current for heating. The concrete cover is arch-shaped.

A very significant effort is now underway in both Hanford and Livingston to install the seismic isolation system. Vacuum cleanliness requires 'bunny suits' (Fig 5); all of the equipment placed in the vacuum must be cleaned and baked as well, to guard against contamination of the mirrors. Fig 6 is a view after installation, with the bottom table, cylindrical masses and somewhat hidden springs between them, the top 'optics' table, and counterweights (emulating the final load) all visible.

The test masses, fused silica 25cm in diameter, are carefully characterized in a metrology interferometer (Fig 7), and mounted in a cage with a simple wire loop. A detail of the point of departure of the wire is seen at the bottom left. The optical losses are determined by the polish and coating (and its cleanliness), and the mechanical losses are the point of connection with thermal noise, and so excruciating attention must be given to every detail.

The optics are installed (Fig 8) in the vacuum system and given an initial alignment sufficiently precise that the reflected beam will be correctly aligned to within one beam tube radius (0.5 m) over the length of the beam tube (4 km). Fancy surveying!

Our last image (Fig 9) shows a part of the optical table carrying the Pre-Stabilized Laser and some of the Input Optics (the University of Florida's contribution). The cylindrical vacuum system contains the frequency reference cavity for the laser, and the rectangular block of fused silica (developed at Stanford) is an optical cavity used in transmission to 'clean' the optical beam.

Our schedule calls for first tests of an interferometer using just the optics in the main building for this summer, with the full 4km paths included in the fall of '99. Please visit one of the sites if you are in the vicinity; contact and other information can be found at http://www.ligo.caltech.edu.

Figure 1: A view from space of the Livingston Observatory (www.terraserver.microsoft.com).

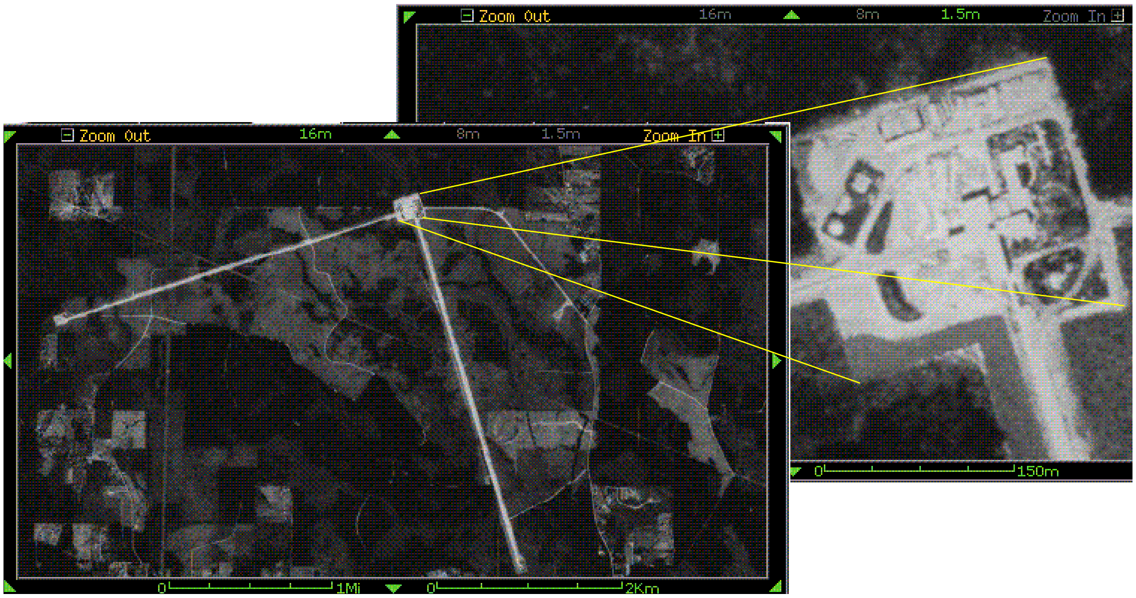
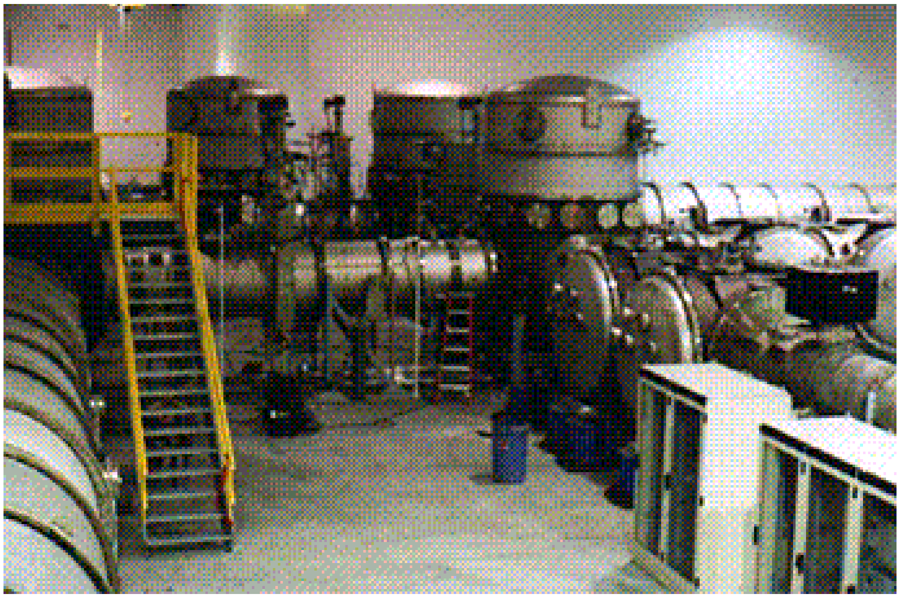


Figure 2: and from a bit closer to earth.

Figure 3: View of the corner station vacuum equipment at Hanford, completed



Fgure 4: The beamtube bakeout insulated and undergoing its ‘bakeout’

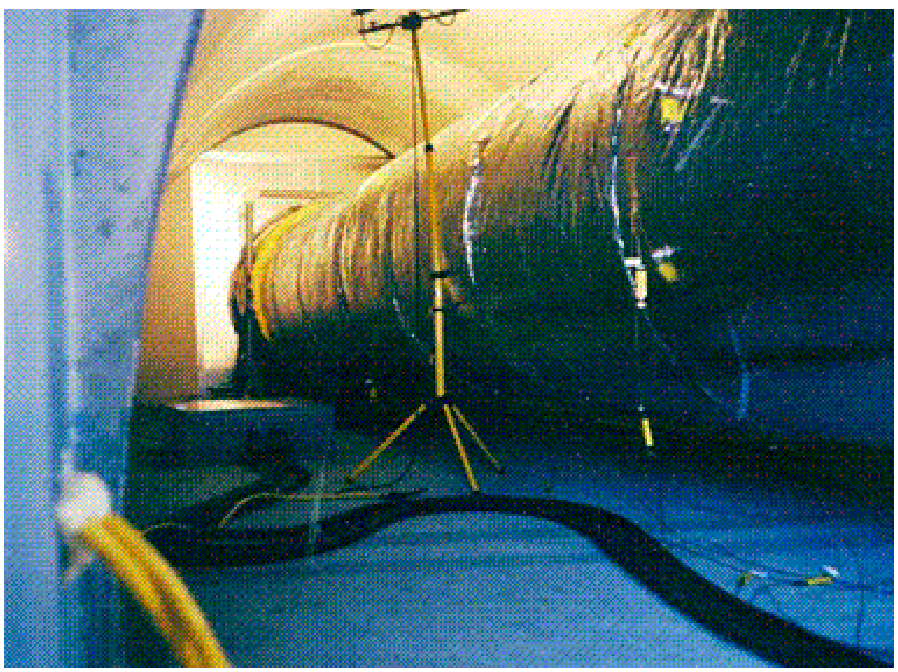


Figure 5: Installation of a HAM seismic isolation system:

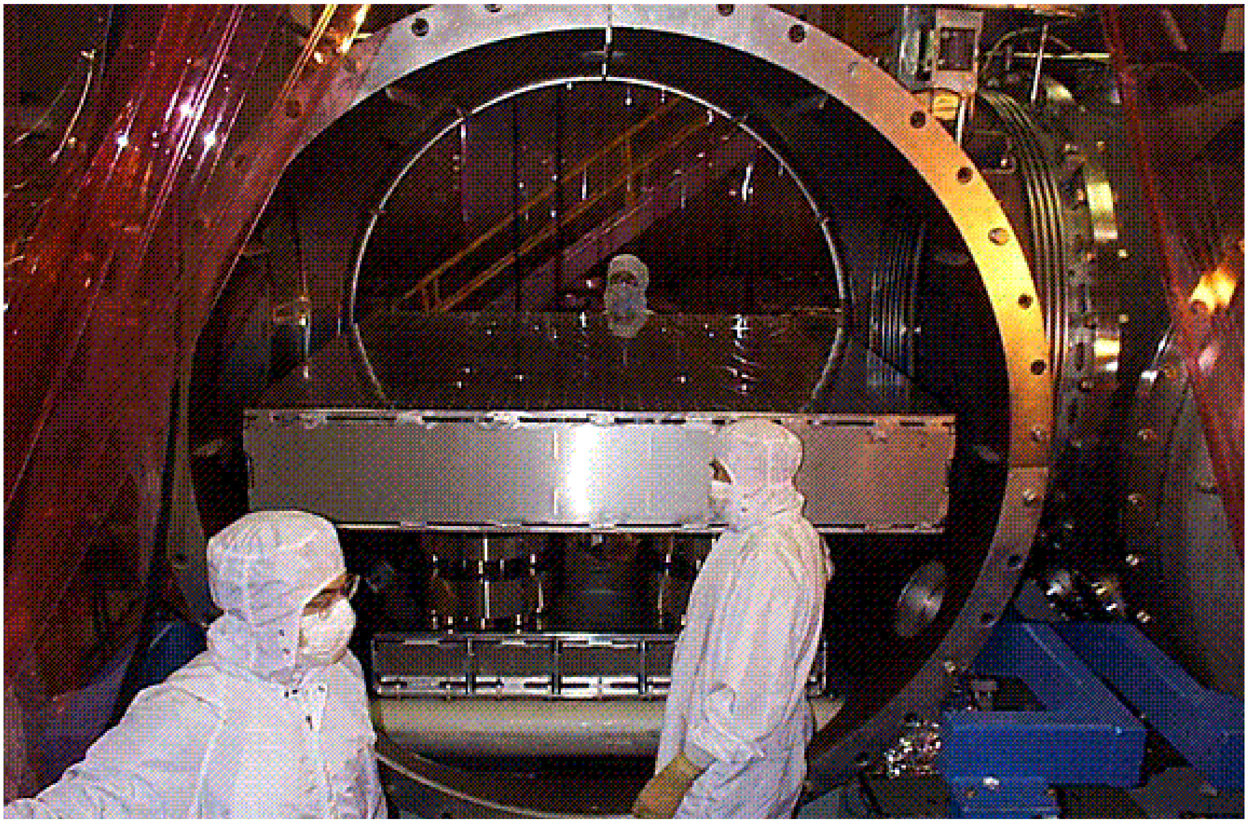


Figure 6: And installed:

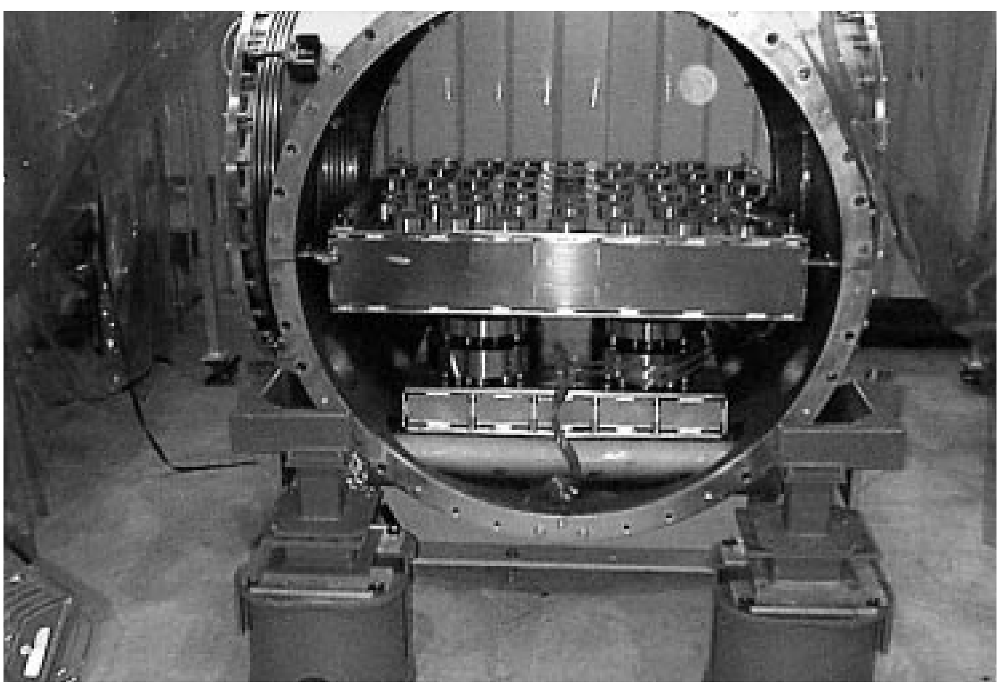


Figure 7: Views of a test mass in optical metrology and as mounted in a suspension cage

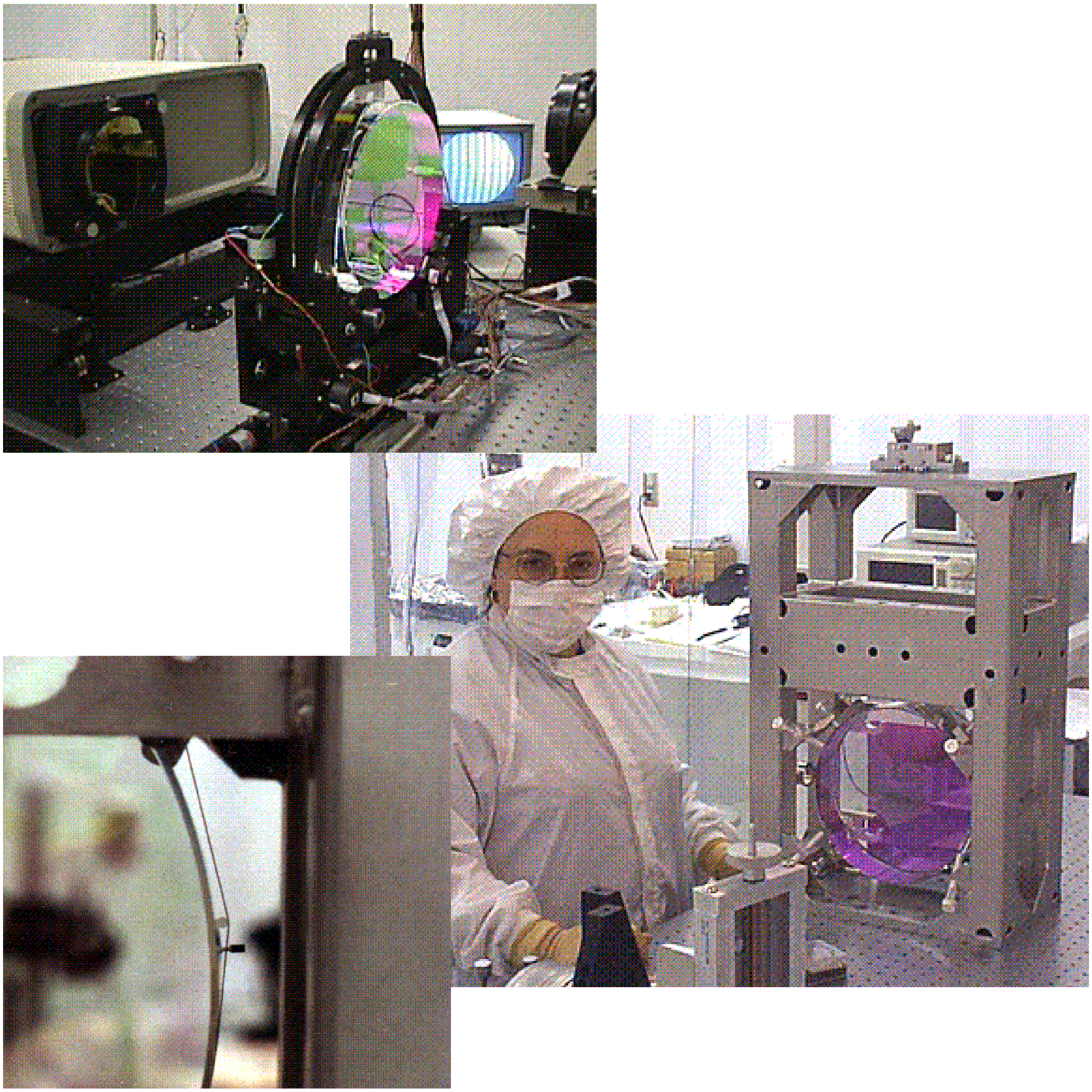


Figure 8: An optic in pre-alignment

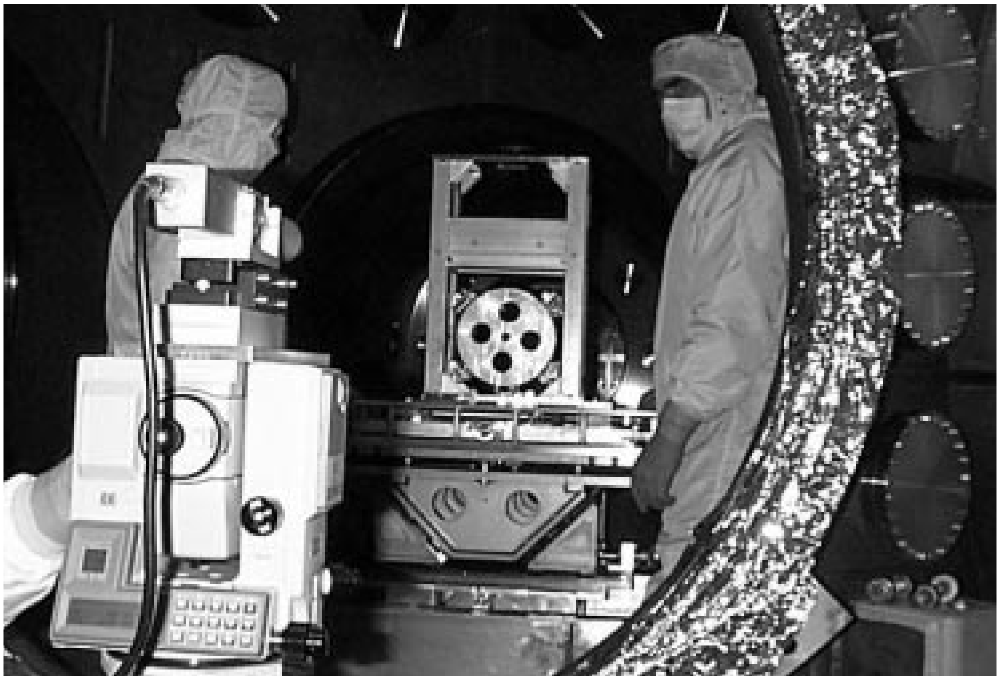
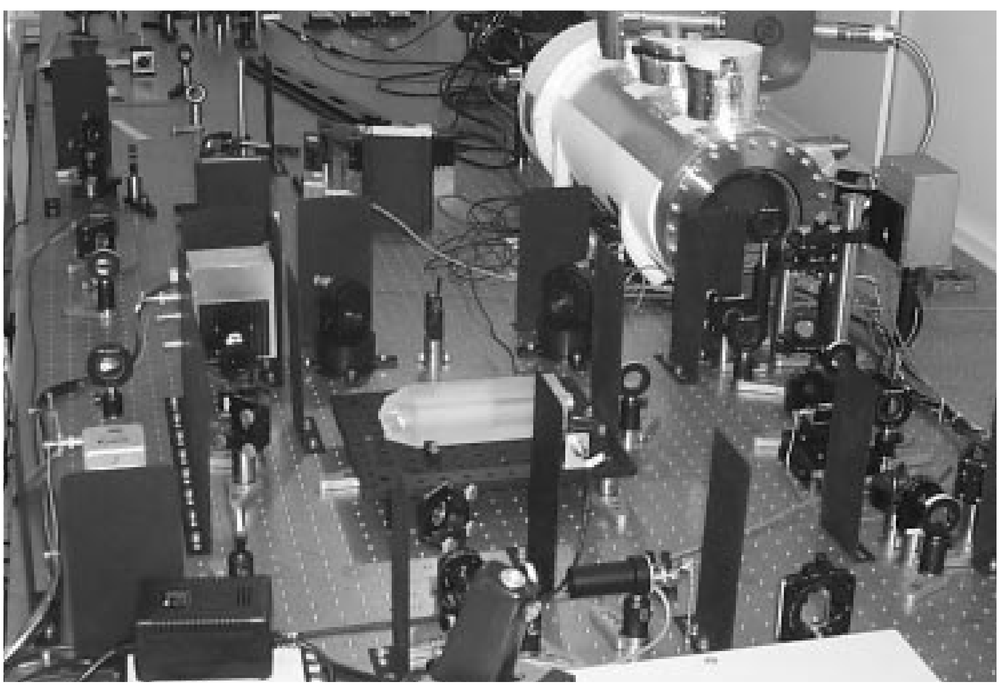


Figure 9: the Pre-Stabilized Laser as installed at Hanford:



Bicentenary of the Cavendish Experiment" Conference

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The measurement of G has become a popular occupation following the announcement a few years ago of widely discrepant new G values — most notably a value reported by the German PTB (NIST-equivalent) lab which is more than half a percent away from the accepted "CODATA" value (see volume 4 of this Newsletter). Thus the celebration of the 200th anniversary of Cavendish's G measurement with a conference in London last November, sponsored by IOP and organized by Terry Quinn of the BIPM and Clive Speake, drew a lively crowd of G measurers to Cavendish's turf. Twelve groups actively pursuing G measurements were represented; six of these announced new or updated G values:

Lab	G $\times 10^{11}$	(ppm)	$G - G_{CODATA}$ (σ)	$G - G_{PTB}$ (σ)
New Zealand MSL	6.6742(6)	90	1.5	-51
Zurich	6.6749(14)	210	1.4	-27
Wuppertal	6.6735(9)(13)	240	0.5	-25
JILA	6.6873(94)	1400	1.6	-3
BIPM	6.683(11)	1650	0.9	-3
Karagioz (Russia)	6.6729(5)	75	0.3	-57
Luther/Towler 1982	6.6726(5)	64	–	-58
PTB 1995	6.71540(56)	83	42	–

Here the comparisons with CODATA and PTB in standard deviations reflect uncertainties in both numbers compared. The last two lines give the 1982 result of Luther and Towler (on which the CODATA value is based, after doubling the assigned uncertainty), and the puzzling 1995 PTB result.

All six new results are higher than but roughly consistent with the CODATA value. The PTB value remains a mystery, not to be lightly dismissed — the CODATA committee will have difficult decisions to make in its next round of assessments! No lab yet feels it has surpassed the 64 ppm accuracy that Luther and Towler assigned to their 1982 measurement, although a number of groups target accuracy of 10 ppm or better.

The twelve approaches to G measurement are remarkable in their variety – no two are very similar in technique. Heedful of Kuroda's caution about the perils of anelasticity, all but two of the experiments either avoid the use of a torsion fiber or use a fiber in a mode such that its internal strains are negligible. The New Zealand MSL lab compares the torque on a torsion pendulum with that due to an electrostatic force which is in turn calibrated in terms of the angular acceleration it produces on the pendulum in a separate experiment. The Zurich group uses a beam balance to weigh kilogram masses in the presence of mercury filled steel tanks – this group anticipates greatly increased accuracy when some systematics issues are resolved. Wuppertal measures the effect of source masses on the spacing of a pair of suspended masses which form a microwave Fabry-Perot cavity, and aims for accuracy better than 100 ppm. JILA uses its free-fall gravimeter to measure the change in g produced by a movable tungsten ring mass. BIPM uses a torsion balance suspended by a thin flat metal strip; its dominant torsional restoring force is gravitational, thus minimizing anelastic dangers. BIPM plans to use its instrument in two ways to measure G, in both a static displacement mode and a "time of swing" dynamic mode, aiming for a solidly reliable measurement at a 100 ppm level. The Russian lab uses a torsion pendulum in the classic dynamic mode used by Luther and Towler; it has been troubled in the past by poorly understood drifts.

Work in progress was reported by additional groups: Luther at LANL is developing an instrument which will use a bifilar suspension which, like the BIPM strip suspension, has a restoring torque which is dominantly gravitational in origin thus circumventing anelasticity issues. The University of Washington and Irvine labs are both building instruments which use thin plate pendulums suspended in nearly pure quadrupole gravitational field gradients produced by special source mass configurations. The Washington approach elegantly avoids fiber-related problems by servoing its pendulum to a continuously rotating platform whose measured periodic angular acceleration reflects that of the pendulum, while the pendulum fiber never twists significantly. The Irvine instrument uses the classic ”time of swing” dynamic method, operating at 2K with a high Q fiber whose anelastic effects should be sufficiently small and well understood to not limit the measurement's accuracy. Both the JILA group and the Taiwan group of W.T. Ni discussed plans for G measurements using a scheme like Wuppertal's but using an optical rather than microwave interferometer as distance gauge. The SEE project was presented, which hopes to determine G and test other aspects of Newtonian gravity using measurements of “horseshoe” trajectories of test masses projected toward a field mass within a long cylindrical space capsule. Development at the Politecnico di Torino of a G measurement using a pendulum swinging between two mass spheres was discussed.

The conference also featured fascinating talks by G. Gillies and I. Falconer on the history of G measurements and the painfully shy but highly skilled man Cavendish. Thibault Damour lectured on the theoretical importance of measurements of G and its possible dependencies on mass composition, distance, and time. Thibault reminded us that, contrary to popular belief, G is NOT the least well known fundamental constant – that distinction belongs to the strong coupling constant!

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Eighth Midwest gravity meeting

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The Eighth Midwest Relativity Meeting was held September 24—25 at North Dakota State University in Fargo. The transparencies are electronically published on the MWRM8 website

http://www.phys.ndsu.nodak.edu/mrm8.html

The meeting was kicked off with a bang by Beverly Berger's characterization of singularities for generic matter. In her work she assumed the existence of only one Killing vector, and discussed the outlook for the case of no symmetries. Bob Wald presented an intriguing discussion of the Path Integral in quantum gravity, and after emphasizing our incomplete understanding of both the wave function and the path integral, compared it with the parameterized Schödinger quantum mechanics, in the context of tunneling, and showed there was a critical parameter for tunneling. Rich Hammond demonstrated how a cosmological term gradient breaks the principle of equivalence and gave an upper bound for its gradient based on laboratory results.

Jean Krisch discussed cosmology in D+1 dimensions, and showed that as D increased the Planck temperature decreased. Jim Wheeler explained his conformal theory of gravity in 4+4 dimensions, while Terry Bradfield used a "compensating" field to obtain conformal invariance. Mike Martin examined gauge fields in the context of a classical unified theory of gravity and electromagnetism.

Gabor Kunstatter made his debut at MWRMs with a discussion on the entropy of black holes (why is it so large?) in gravitation with a scalar field. Brett Taylor showed how a scalar field can make the black hole temperature zero, and Leopoldo Zayas discussed procedures for obtaining black hole entropy using string theory methods.

Bill Hiscock gave an overview of the OMEGA project, which, if chosen, will be one of NASA's new smaller missions which will orbit an interferometer around earth-moon. He emphasized that there are six known white dwarf binaries that OMEGA should detect. Shane Larson calculated the noise in the interferometer without resorting to the usual long wavelength approximation. Ted Quinn calculated the force on a scalar particle in curved space including the radiation reaction force. Ken Olum explained fast travel in terms of negative mass, or Casimir-type energy. We all know the picture with Einstein standing in front of the blackboard with "$R_{i\kappa} = 0?''$. Dwight Vincent gave a fascinating account of this picture, from its photo-shoot in 1931 at the Mt. Wilson Observatory, to modern commercialization of it. Discussions focused on the meaning of the question mark, and what physics was actually being questioned.

Charro Gruver derived the material action for gravitation with torsion, and showed how to obtain the correct conservation law for angular momentum plus spin. Bill Pezzaglia derived equations of motion for particles with spin in the presence of torsion by generalizing the Lagrangian to include an area term.

Robert Mann presented an interesting exact solution for the N-body problem in two dimensional gravity with a scalar field, and showed, for example, that when the Hamiltonian becomes large with respect to $3mc^2$ the relativistic effects are fully evident. Thomas Baumgarte defined a new conformal 3-metric to modify the ADM formalism, and discussed geodesic slicing vs. harmonic slicing with regard to numerical solutions.

Ed Glass gave an illuminating discussion of the Vaiyda metric, and showed that a generalization leads to both a null fluid and string fluid. Ivan Booth discussed boundary terms and Steve Harris discussed the future causal boundary and multiply warped spacetimes. Mike Ashley discussed the properties of the a-boundary as a topological object. Homer Ellis explained space-time-time, and 'dark hole' solutions with singularities. Ian Redmount examined quantum field theory states in Robertson Walker cosmology and claimed that particles can only be well defined in an open universe. This created a lively discussion with Wald pointing out that his results are probably not valid for massless particles (such as photons). The discussion continued when Berger, Mann, and John Friedmann joined the fray.

Marc Paleth reported on the Wigner function and the relation between its peaks and regions of high correlation. Another lively discussion followed when Zayas questioned the $\hbar \to 0$ limit. Andreas Zoupas explained how environmental de-coherence arises from the master equation and the reduced equation. James Geddes gave a detailed account of the measure in the path integral from the point of view of a collection of subsets.

Excitement grew as meeting neared its end with John Friedmann's fascinating discussion of how, in a window between 10^9 and 10^{10}, perturbations in a rotating neutron star can grow. Finally, Abraham Ungar used the law of Einstein velocity addition to generalize the laws of motion, and suggested tests for his theory.

GWDAW '98

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On 19–21 November 1998, nearly 100 researchers from Australia, Asia, Europe and North America gathered in Central Pennsylvania to attend the Third Gravitational Wave Data Analysis Workshop, held under the auspices of Penn State's Center for Gravitational Physics and Geometry.

Like the first GWDAW, hosted by MIT in December 1996, GWDAW'98 was organized as a workshop. There were only a small number of short (typically 15 minutes) invited talks, each of which introduced or commented on an outstanding challenge in gravitational wave data analysis. Each talk was followed by extended, moderated discussion (typically 45 minutes) among all the participants. Each invited speaker was admonished by the organizing committee to speak to the future: to look, not backward to the achievements of yesterday, but forward to the challenges ahead and how they might be addressed.

To provide focus for the meeting, the organizing committee identified four different areas of study that would benefit from intense, focused discussion in a workshop setting. Speakers were chosen and the workshop was organized around the subjects of data diagnostics, upper limits and confidence intervals, LISA data analysis challenges, and collaborative data analysis.

The workshop's first morning began an orientation: a series of status reports given by representatives of the four different interferometer projects currently under construction — GEO 600 (B. S. Sathyaprakash), LIGO (A. Lazzarini), TAMA 300 (N. Kanda and T. Tanaka), and VIRGO (A. Vicere') — with an emphasis on their developing plans for data handling and analysis.

Following lunch, the participants turned to the discussion of *data diagnostics:* the use of the data channel itself as a diagnostic monitor of both the instrument's health and the usefulness of the signal channel for analysis. Dr. S. Vitale (University of Trento) described a new, automated data quality monitoring system that has been developed and installed on the AURIGA cryogenic acoustic detector. Two components of this system were of particular interest to the workshop participants: the first was the requirements it placed on the distribution of the signal channel output over hour-long intervals; the second was the requirement of consistency in the excitation amplitude of the antenna's two resonant modes.

Following this discussion, Dr. S. Mukherjee (Penn State) described the development of a *Kalman Filter* that can extract from the signal channel of an interferometric detector the amplitude and phase of the mirror suspension violin modes. Passing gravitational waves do not excite these modes, while technical mechanical noise sources that move the interferometer test masses do; thus, the suspension modes are a sensitive monitor of mechanical disturbances masquerading as gravitational waves. The wide-ranging discussion that followed included the use of the Kalman predictor as a means of reducing the data dynamic range and, possibly, the removal of the lines before analysis for gravitational wave signals.

The afternoon was rounded out by a presentation by Drs. N. Kanda (Miyagi University of Education) and D. Tatsumi (Institute for Cosmic Ray Research, University of Tokyo), who outlined of the TAMA detector calibration scheme and discussed some of the the effects of calibration error on the ability to reliably detect and identify the parameters of gravitational wave sources.

Despite their unprecedented sensitivity and bandwidth, there is no guarantee that the first generation of interferometric detectors will detect directly any sources. Nevertheless these instruments can — at the very least — set interesting and provocative upper limits on source strengths and rates. The second morning of the workshop was given-over to a discussion of the use of data from gravitational wave detectors to set upper limits.

Four talks punctuated a very animated discussion. The morning began with a tutorial, including several worked examples, on the construction of confidence intervals and credible sets, given by Dr. S. Finn (Penn State University). Two lessons were evident in this presentation: the first, that the analysis involved in the construction of upper limits and confidence intervals is as involved as that which goes into deciding upon detection or measuring parameter values, and the second, that the procedures for constructing confidence intervals and credible sets involve choices, and that these affect quantitatively the upper limits or confidence intervals derived.

Following this tutorial, Dr. S. Mohanty (Penn State University) described how, even in the absence of a known waveform, one can set upper-limits on the gravitational wave strength from gamma-ray bursts or other potential gravitational wave sources associated with an astrophysical trigger. After a lengthy discussion period, Dr. B. Allen (University of Wisconsin, Milwaukee) discussed an analysis of the LIGO 40M prototype November 1994 data set for binary inspiral signals. Focusing on the largest "detected" signal in the data set, this collaboration placed what might be termed an upper limit on the possible sets of upper limits that could arise from a more detailed analysis. Finally, Dr. M. Papa (Albert Einstein Institute) inaugurated a discussion of several different methods for searching for weak periodic gravitational wave signals in long stretches of data.

The afternoon of the first day focused on data analysis challenges associated with LISA: the proposed Laser Interferometer Space Antenna. LISA is currently being considered by NASA as a joint ESA/NASA mission, with a potential launch data as early as 2007. LISA has a much greater immediate potential for detecting directly gravitational waves from known astrophysical sources; however, the challenges of LISA data analysis are different than for ground-based interferometers and it is important to show now that LISA's promise can be realized through the analysis of the data it would collect. Four talks, spread over an afternoon of discussion, focused the workshop's attention on LISA's current status (Dr. S. Vitale, University of Trento), data analysis challenges (Dr. R. Stebbins, JILA and University of Colorado), ability to direct the attention of astronomers to imminent activity in different parts of the sky (Dr. A. Vecchio, Albert Einstein Institute), and what turns out to be the unimportance of gravitational lensing of cosmological sources for LISA (Dr. C. Cutler, Albert Einstein Institute).

The final session of the conference was devoted to an animated discussion on collaborative data analysis. There is a general agreement that the joint analysis of data from all simultaneously operating detectors will lead to more constraining upper limits, greater confidence in reported detections, greater measurement precision, and more information about observed sources. There are, however, practical impediments to collaborative data analysis. These include the different "personalities" of the experimental apparatus, deriving from their great complexity When different teams design, build, commission and characterize their instruments, where resides the common knowledge required to carry out an analysis that makes sophisticated use of the multiple data streams?

This problem has been tackled by the acoustic detector community and some of the lessons they have learned were discussed by Dr. G. Pizzella (University of Rome "Tor Vergata"). Other communities face the identical problem: Dr. B. Barish (Caltech) described the mechanism that the neutrino detection community has developed for data sharing. Finally, Dr. R. Weiss (MIT) closed out the workshop with a final presentation on the organization of data analysis in the COBE project and his own perspective on the importance of cooperative data analysis. Weiss identified what may be one of the more difficult problems we face: the cultural transition from the model of the scientist as an individual entrepreneur, who keeps hold of an idea and the credit for it, to the collaborative model, where ideas are shared, the community accepts the credit for the accomplishments, and the participants take their reward from being part of the community.

Bad Honnef seminar

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A seminar with the title 'Mathematical Problems in General Relativity' took place in Bad Honnef, Germany, from 7th to 11th September 1998. This seminar, with about sixty participants from eighteen countries, was organized by Herbert Pfister (University of Tübingen) and Bernd Schmidt (AEI Potsdam) and financially supported by the Heraeus Foundation. It was primarily aimed at graduate students and so strong emphasis was put on the pedagogical nature of the talks. At the same time it was intended to give a point of entry to recent results in the area of mathematical relativity.

A mathematical understanding of general relativity requires knowledge of the solution theory of the Einstein constraints and evolution equations and the corresponding mathematical background. Robert Beig gave an introduction to the constraints together with a discussion of identifying spacetime Killing vectors in terms of initial data and giving a four-dimensional characterization of special solutions of the constraints, such as the multiple black hole solutions of interest in numerical relativity. Oscar Reula treated the basic theory of the evolution equations. He also presented a more general account of the nature of hyperbolicity of systems of partial differential equations and new results on writing the Einstein equations expressed in Ashtekar variables in symmetric hyperbolic form.

A subject which was given particular attention was that of asymptotically flat vacuum spacetimes with Helmut Friedrich talking for four hours on his program to investigate the consistency of the classical conformal picture with the field equations and Alan Rendall talking for four hours on the theorem of Christodoulou and Klainerman on the nonlinear stability of Minkowski space. Friedrich presented his results on the stability of de Sitter and anti-de Sitter spacetimes as well as new developments concerning restrictions on asymptotically flat initial data related to smoothness of null infinity. As explained in talks by Gabriel Nagy, insights from the anti-de Sitter case were important in the recent existence theorem for the initial boundary value problem for the vacuum Einstein equations by him and Friedrich. Rendall explained some of the analytical techniques used in the Christodoulou-Klainerman proof such as energy estimates (also prominent in Reula's talk), the Bel-Robinson tensor, bootstrap arguments and the null condition. Lars Andersson showed how some of these techniques, in particular the Bel-Robinson tensor, have been applied to a class of cosmological spacetimes in his work with Vincent Moncrief on the stability of the Milne model. This opens up the possibility that the Christodoulou-Klainerman result may not stand in splendid isolation much longer. Yvonne Choquet-Bruhat, in a talk on geometrical optics expansions for the Einstein equations, told how this reveals an 'almost linear' property of these equations, exceptional among hyperbolic systems, which is related to the null condition.

Matter was not neglected at the conference either. Herbert Pfister and Urs Schaudt described their progress towards constructing solutions of the Einstein-Euler equations with given equation of state representing rotating stars. Lee Lindblom talked on the inverse problem of reconstructing the equation of state given data on masses and radii of corresponding fluid bodies. In constructing fluid bodies it is always wise to keep an an eye on the corresponding Newtonian problem. Jürgen Ehlers gave an introduction to his mathematical formulation of the Newtonian limit which can be used to give a conceptually clear approach to this. Gerhard Rein summarized our present knowledge on the gravitational collapse of collisionless matter, including his recent numerical work with Rendall and Jack Schaeffer on the boundary between dispersion and black hole formation for this matter model. From the point of view of exact solutions, Gernot Neugebauer spoke on the inverse scattering method and Dietrich Kramer described an approach to producing null dust solutions.

The fact that the whole seminar took place in the Physics Centre of the German Physical Society in Bad Honnef and that all participants were accomodated in that building provided ample opportunity for formal and (particularly on the evening with free beverages) less formal discussions.