MATTERS OF GRAVITY

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

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Contents

GGR News:

Research briefs:

Conference reports:

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DISCLAIMER: The opinions expressed in the articles of this newsletter represent the views of the authors and are not necessarily the views of APS. The articles in this newsletter are not peer reviewed.

Editorial

The next newsletter is due September 1st. This and all subsequent issues will be available on the web at `https://files.oakland.edu/users/garfinkl/web/mog/` All issues before number **28** are available at `http://www.phys.lsu.edu/mog`

Any ideas for topics that should be covered by the newsletter, should be emailed to me, or Greg Comer, or the relevant correspondent. Any comments/questions/complaints about the newsletter should be emailed to me.

A hardcopy of the newsletter is distributed free of charge to the members of the APS Topical Group on Gravitation upon request (the default distribution form is via the web) to the secretary of the Topical Group. 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.

David Garfinkle

Correspondents of Matters of Gravity

- John Friedman and Kip Thorne: Relativistic Astrophysics,
- Bei-Lok Hu: Quantum Cosmology and Related Topics
- Veronika Hubeny: String Theory
- Beverly Berger: News from NSF
- Luis Lehner: Numerical Relativity
- Jim Isenberg: Mathematical Relativity
- Lee Smolin: Quantum Gravity
- Cliff Will: Confrontation of Theory with Experiment
- Peter Bender: Space Experiments
- Jens Gundlach: Laboratory Experiments
- Warren Johnson: Resonant Mass Gravitational Wave Detectors
- David Shoemaker: LIGO Project
- Stan Whitcomb: Gravitational Wave detection
- Peter Saulson and Jorge Pullin: former editors, correspondents at large.

Topical Group in Gravitation (GGR) Authorities

Chair: Stan Whitcomb; Chair-Elect: Steve Detweiler; Vice-Chair: Patrick Brady. Secretary-Treasurer: Gabriela Gonzalez; Past Chair: David Garfinkle; Delegates: Lee Lindblom, Eric Poisson, Frans Pretorius, Larry Ford, Scott Hughes, Bernard Whiting.

GGR program at the APS meeting in Washington D.C.

David Garfinkle, Oakland University garfinkl-at-oakland.edu

We have an exciting GGR related program at the upcoming APS "April" meeting (this year in February) in Washington D.C. Our chair-elect Steve Detweiler did an excellent job of putting together this program. At the APS meeting there will be several invited sessions of talks sponsored by the Topical Group in Gravitation (GGR). The large number of sessions sponsored by GGR means that our Topical Group has become one of the most important units at this meeting: only the Divisions of Astrophysics, Particles and Fields, and Nuclear Physics have a larger presence at the April meeting.

The invited sessions sponsored by GGR are as follows:

Quantum Black Holes: Theory and Applications
Finn Larsen, Astrophysical Black Holes in String Theory?
Glenn Starkman, Realistic (?) Black Holes at the LHC
Sean Hartnoll, Holographic Approach to Condensed Matter Physics

Probing Strong-Field Gravity with Observations of the Galactic Center Black Hole
David Merritt, Probing Strong Field Gravity at the Galactic Center Using Stellar Motions
Sheperd Doeleman, Observing an Event Horizon: (sub)mm Wavelength VLBI of SgrA*
Avery Broderick, Nature of the Black Hole in the Center of the Milky Way

Numerical Relativity and Astrophysics
(joint with DCOMP)
Carlos Lousto, Statistical Studies of Spinning Black Hole Binaries
Matthew Duez, What Happens When Black Holes and Neutron Stars Merge?
Scott Noble, Seeing Spacetime by Proxy: Binary Black Holes in Gaseous Environments

Earth, Sky and Moon: Gravity Tests Across 13 Orders of Magnitude
(joint with GPMFC)
Stephan Schlamminger, Laboratory Tests of the Inverse Square Law of Gravity
Pierre Touboul, ESA's GOCE Gravity Gradiometer Mission
Tom Murphy, Advancing Tests of Relativity via Lunar Laser Ranging

Ground-based Interferometers on the Road to Gravitational Wave Astrophysics
Rana Adhikari, The LIGO and VIRGO Gravitational Wave Detectors
Peter Shawhan, Multi-Messenger Astronomy and Astrophysics with Grativational Wave Transients
Xavier Siemens, Science of Continuous Gravitational Wave Signals: Periodic Waves and the Stochastic Background

Gravity in Extreme Conditions
(joint with DCOMP)
Christian Ott, Computational Models of Stellar Collapse, Core-Collapse Supernovae, and Black Hole Formation
Frans Pretorius, Aneesur Rahman Prize for Computational Physics Talk: Black Hole Collisions
Steve Liebling, Status Report on Black Hole Critical Behavior

The GGR contributed sessions are as follows:

Lorentz Symmetry in Gravitation; Followed by LISA Developments
(joint with GPMFC)

Gravitational Collapse and Numerical Relativity

Observational Implications of Gravitational Waves
(joint with DAP)

Dynamics of Black Holes

Modeling Black Hole Binaries

Interpretation of Gravitational Wave Forms from Compact Binaries

Black Holes

Approximations in General Relativity

Numerical Simulations of Black Holes and Neutron Stars

Gravitational Waves from Neutron Stars

Quantum Aspects of Gravitation

Equivalence Principle and Precision Gravity Tests
(joint with GPMFC)

Advances in Ground-Based Gravitational Wave Detection

Foundational Aspects of General Relativity

we hear that . . .

David Garfinkle, Oakland University garfinkl-at-oakland.edu

Frans Pretorius has been awarded the APS Aneesure Rahman Prize for Computational Physics.

Stefan Hollands has been awarded the Xanthopoulos Prize.

Nicolas Yunes has been awarded the Ehlers Thesis Prize.

Victor Taveras has been awarded the Bergmann-Wheeler Thesis Prize.

Manuella Campanelli was elected Vice-Chair of GGR; and Laura Cadonati and Luis Lehner were elected members at large of the GGR executive committee.

Manuela Campanelli, Karsten Danzmann, Katie Freese, Joseph Giaime, Jens Gundlach, Craig Hogan, Keith Riles, and Matt Visser have been elected as APS Fellows.

Hearty Congratulations!

Supernovae modelling

Ian Hawke, University of Southampton I.Hawke-at-soton.ac.uk

Supernovae have repeatedly spurred scientific advances in understanding the "extra-solar" universe. This was most recently illustrated by SN1987A, the first supernova observed on Earth in every electromagnetic band, as well as being the first object (except the Sun) to be detected in neutrinos. The huge scientific effort to understand these observations, reviewed near the time by [1, 2], is ongoing with a range of groups modelling the details of the collapse and explosion. With suggestions that a galactic supernova could be detectable using gravitational waves by current detectors such as LIGO, and that such a detection may shed light on the supernova process (for a review see [3]), the specific importance of this problem to the gravity community is clear; much of this article will concentrate on this aspect. What is less clear remains the answer to the central problem: what makes a supernova explode?

An outline of the early stages of collapse is simple enough to sketch (for more detail see, e.g., [4]). If a main sequence star is sufficiently massive then eventually the pressure support from nuclear burning is insufficient to support it against its own self-gravity, leading to collapse. When nuclear densities ($\rho \approx 10^{14}\,\mathrm{g\,cm^{-3}}$) are reached the degenerate matter is less compressible, leading to increased pressure support in the core and an outwardly propagating "bounce" shock. This is driven from the edge of the decelerated core into the outer layers which continue to fall supersonically in.

At this point the viability of the explosion becomes a competition between the energy of the bounce shock and that of the infalling matter. The strength of the shock is largely determined by the mass and composition of the progenitor, but is also influenced by the approximations in the modelling (e.g., the use of a relativistic instead of a Newtonian gravity model leads to more compact cores; interestingly, this does not necessarily lead to larger gravitational wave amplitudes, as shown by [5]). Although some early simulations with extreme progenitors or equations of state suggested that a "prompt" shock explosion was possible, all current calculations agree that the energy lost as the outgoing shock dissociates the infalling matter to nucleons causes the bounce shock to stall.

To initiate the explosion the shock needs to be revived. The precise mechanism for this is uncertain, with different models and simulations suggesting different key features. A central model is the neutrino heating mechanism ([6, 7]), where the neutrinos remove energy from the hot core, some of which is deposited behind the stalled shock, heating the matter and re-energizing the shock. The existence of various hydrodynamical instabilities behind the shock may amplify this mechanism away from spherical symmetry. A more recent suggestion is the acoustic mechanism ([8, 9]) where strong g-modes excited in the core during collapse transfer energy outwards via sound waves, steepening into shocks and depositing their energy to revive the stalled shock. Finally, there remain suggestions that magnetic fields wound up during collapse could convert rotational to kinetic energy leading to the explosion (as reviewed by e.g. [10]).

Modelling each of these scenarios and distinguishing between them clearly requires detailed, high accuracy numerical simulations of hydrodynamics in strong field gravity with radiation transport, taking into account the composition and reactions of the stellar material and also the magnetic field. The importance of convective and turbulent motion also means a multi-dimensional treatment is essential. Despite recent advances (illustrated by simulations such as [11, 12, 13]) a comprehensive treatment remains out of reach. With detailed tests (see [14, 15]) suggesting that a modified Newtonian potential is a sufficient model of gravity to capture all of the relevant features there is little need for full numerical relativity. In addition, magnetic fields are not currently believed to be an important factor in the explosion due to the slow rotation of the best progenitor models ([16]). The modelling of the neutrino transport and the core hydrodynamics is then key.

In recent simulations (see in particular [11]) the focus has moved away from the acoustic mechanism, which has been difficult to reproduce away from the original scenarios, towards a neutrino-driven explosion aided by convection (see e.g. [17]) and dynamical instabilities behind the stalled shock. The main feature is that the stalled accretion shock is unstable to non-radial perturbations, with the low ℓ modes showing the highest growth. This Standing Accretion Shock Instability (SASI), first investigated by [18], is now suggested to be an essential driver of the explosion mechanism. The SASI causes the shock to slosh back and forth, pushing the shock further out and increasing the range over which neutrinos can deposit energy to revive the shock. The precise nature of the interaction between the SASI and the core remains unclear (see e.g. [19, 20]), as does the effects of the progenitor mass and the importance of 3 rather than 2 dimensional numerical simulations (see [13] for early results). What is clear is that the gravitational wave signal post-bounce will contain considerably more information about the physics (for results directly related to the SASI see [12]) than the signal around bounce, which has been shown by [21] to be fairly generic.

The achievement of multi-dimensional accurate numerical simulations of core collapse with detailed approximations of radiation transport, hydrodynamics and gravity have given hope that the essential mechanisms behind supernova explosions are on the way to being understood. The complexity and sheer length of time required for these simulations are problems that can and will be overcome. Should we be lucky enough for a repeat of SN1987A, the information gained through combining gravitational wave detections with neutrinos and electromagnetic signals could be spectacular.

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ADM-50

Richard Woodard, University of Florida woodard-at-phys.ufl.edu

2009 was the 50th anniversary of the development by Arnowitt, Deser and Misner of a canonical formalism for general relativity with asymptotically flat boundary conditions. This has been the basis for most subsequent work on the initial value problem in gravity, on numerical general relativity (as applied to neutron star and black hole collisions), on the stability of general relativity and alternate gravity models, and even on cosmological perturbations. It was a major stimulation for the current experiments to detect gravitational waves, and has had many applications to the study of black holes in string theory. The importance of the ADM formalism was recognized by the American Physical Society through award of the 1994 Dannie Heineman Prize in Mathematical Physics to Arnowitt, Deser and Misner.

A conference was held to mark the anniversary over the weekend of November 7-8. It took place in the newly completed Mitchell building on the campus of Texas A&M University in College Station, Texas. Eighty-six participants attended two days of talks. The slides of each speaker's talk are available on the conference webpage at `http://adm-50.physics.tamu.edu` Just click on 'Speakers' and the slides of each talk are there as a pdf file.

The opening talk was given by Jim Hartle, who spoke on work done in the context of minisuperspace with Stephen Hawking and Thomas Hertog about identifying quantum gravitational states which predict approximately classical cosmologies. He closed with three questions for ADM:

1. Fifty years ago what did you think would be the future of quantum gravity?
2. Where do we stand today and what do we have left to do?
3. How do you think today's efforts will appear at ADM-100?

Richard Woodard spoke next on the quantum generalization of the remarkable demonstration by ADM that the self-energy of a classical, charged and gravitating particle is finite. In the subsequent question period Stanley Deser mentioned that this paper (Phys. Rev. Lett. **4** (1960) 375-377) was also the first work on general relativity ever published by Physical Review Letters! Jorge Pullin rounded out the Saturday morning session with report on work with Rodolfo Gambini and Rafael Porto on the problem of time in quantum gravity. He advocated a synthesis of the two main approaches: "evolving Dirac observables" and "conditional probabilities."

A scientific highlight of the conference came Saturday afternoon with back-to-back talks by Zvi Bern and Kelly Stelle on the recent demonstration that $N = 8$ supergravity is on-shell finite at four loop order in $D = 4$ and (the surprise) $D = 5$. Bern described his heroic computation with Carrasco, Dixon, Johansson and Roiban. While paying generous tribute to this work, Stelle explained how one can understand the cancellations, *ex post facto*, from field theoretic nonrenormalization theorems whose protection should fail at seven loop order in $D = 4$ dimensions. Bern disagreed, and pointed to all orders results that can be obtained for a sub-class of diagrams.

Ben Gold from the WMAP collaboration presented the most recent results on the six cosmological parameters of the concordance model, and on the tensor-to-scalar ratio, the dark energy equation of state, exotic perturbation models, running of the scalar spectral index, neutrinos and non-Gaussianity. Bob Wald concluded the Saturday session with a discussion of the important auxiliary structure endowed upon classical field theory by the existence of a Lagrangian or a Hamiltonian.

The conference banquet featured reminiscences of how ADM came to be. Stanley Deser explained that he and Dick Arnowitt began working on gravity because a spin two force carrier seemed like the next frontier after the great successes of spin one QED. They talked of it at a meeting at Neuchatel in the summer of 1958 where Pauli was present. By that time they had reworked gravity into a 3+1 decomposition. Then they were summoned to Princeton by John Wheeler who introduced his "brightest student since Feynman" and Charlie Misner modestly proposed "some ideas that might be relevant." Misner took up the story at this point, explaining how he met his Danish wife through her sister having organized a meeting which he attended. The couple were married in June of 1959 so they could go together to the island of Bornholm where Stanley and his Swedish wife had decided to spend the summer to avoid the heat of Copenhagen. The key ADM work was done on Bornholm from June to August of 1959, although the trio continued through 1961, partly at Brandeis, some at Syracuse and much by phone and letters. At Bornholm they began work in an elementary school which is still standing, though now as a tourist office. When the Danish school started up again they transferred to a now demolished Kindergarten where they had to crouch to use the tiny blackboards. Some of their best work was done there.

Sunday began with Steve Carlip speaking on his suggestion that any theory with approximate conformal invariance near the event horizon gives the Bekenstein-Hawking entropy. Next came Nick Suntzeff who gave a wide ranging talk on using Type Ia Supernovae as tools for precision cosmology. He reminded us all of the history of the subject ("I am not part of the Harvard Group – they are a part of my group"), spoke on results from the ESSENCE Survey, described the goals of the Carnegie Supernova Project and ended by discussing modified gravity as an alternative to either dark matter or dark energy. Rainer Weiss closed the morning session with a review of gravitational wave detection. Among many other things, he noted that Stanley Deser sat on the 1983 NSF Advisory Committee which recommended LIGO, and was even one of three on the Subcommittee which actually drafted the report.

A distinctive Texas flavor was added to Sunday's lunch by Phil Yasskin who organized an expedition to a local barbeque restaurant. Gorged, and only a little late, we returned to hear Bernard Schutz describe numerical relativity analyses of compact mergers. Although avoiding numerical instabilities requires reformulating the equations along the lines worked out by Baumgarte, Shapiro, Shibata, and Nakamura, the "ADM notation and conceptualization remain the language of numerical relativity". Chris Pope spoke on exact solutions to general relativity in higher dimensions. One point he made, fortified by examples, is that some of the familiar 4-dimensional uniqueness theorems no longer apply. Mike Duff closed the conference by describing a correspondence between the entanglement measures of qubits in quantum information theory and black hole entropy in string theory.