Report on MICRA2009
Workshop on Microphysics in Computational Relativistic Astrophysics
Copenhagen, 24-28 August 2009

Summary

Modern astronomical instruments, both ground-based and in space, have revealed many energetic phenomena in which the physics and astrophysics of matter and radiation at high densities and the effects of general relativity play a central role. Understanding these phenomena is a great challenge, and over the past two decades much progress has been made in developing numerical methods for simulating dynamical general-relativistic gravitational fields, hydrodynamic processes, and radiation transport. There has also been significant progress in understanding nuclear and particles physics at a fundamental level, but there has not been a corresponding improvement in many aspects of the microscopic physics input, such as the equation of state of hot dense matter and rates of neutrino processes, used in simulations.

The overall aim of the workshop was to improve the microscopic physics input to numerical simulations of astrophysical phenomena in relativistic astrophysics. Especial emphasis was placed on stellar collapse and supernova physics, and the evolution and coalescence of binary stars, and topics covered included improved microscopic physics inputs (neutrino-matter interactions, equations of state, thermonuclear reaction rates) and computational methods (general relativistic hydrodynamics and magnetohydrodynamics, radiation transport, reaction networks) with an emphasis on approaches that allow for efficient implementation of the improvements in multi-D simulations of relativistic astrophysical systems.

This workshop brought together leading and younger researchers in the field of numerical modeling and microscopic physics of matter and radiation at high densities where effects of general relativity play a central role. A valuable contribution was made by workers coming from related fields, such as stellar physics, where studies of radiation transport (of photons rather than neutrinos) and convection are highly developed. The workshop was organized as a mixture of overview talks, shorter contributions, and time for discussions collaboration in smaller groups and individual work.

The meeting took place at the Niels Bohr International Academy immediately after the summer school on "Stellar Collapse, Compact Objects, Supernovae, and Gamma-Ray Bursts" that was held in Copenhagen during the period 17-21 August, 2009. This provided an opportunity for younger scientists to be prepared for participation in the workshop, and 11 students from the School participated in the workshop. There were 50 participants in total.

Description of scientific content

The workshop brought together people working on a diverse range of problems – from the numerical modelling of astrophysical phenomena to the microscopic physics of interactions in dense matter. In order to improve the physics input to numerical simulations, it is necessary not only to improve understanding of the microscopic physics, but also to have the results of the microscopic calculations in a form that is appropriate for incorporation in numerical codes. To achieve this aim, there needs to be close collaboration between people performing calculations of microscopic physics, and those doing numerical modelling of phenomena.

The workshop consisted of three elements. The first was overview talks, which were intended to lay out the present state of knowledge in a particular area, and to point to challenges for future work. The second element was shorter contributions on topical problems, and the third was time for informal discussion and working together in smaller groups. In making the timetable, ample time for discussion was allowed, so that all the time was not filled with formal presentations. Also participants were encouraged to come for the whole workshop, so that they could participate in the discussions, and attendance for a shorter period just to give a talk was strongly discouraged.

There were 7 half-day sessions devoted to

- Core Collapse Supernova Simulations,
- The High-Density Equation of State,
- Neutrino-Matter Interactions,
- Merging Compact Binaries and Single Neutron Stars,
- Gravity, Hydrodynamics and Magnetohydrodynamics,
- Methods: Transport and Approximations / Gravity, HD, MHD, and
- Nuclei and the Outer Layers of Neutron Stars.

The overview talks served to provide the participants with a common language and background, and helped promote discussion between scientists with different backgrounds. The shorter contributions were mainly on current work, and spotlighted areas where progress was being made. The shorter contributions were made by scientists with very different levels of experience, ranging from senior researchers to young faculty members, to postdocs and graduate students. To avoid overloading the audience, use of the blackboard was strongly encouraged. Most of the presentations may be found on the workshop home page, at `www.micra2009.org ->Talks and Slides`.

For the purposes of the workshop, which was to bring together people from different communities, the number of participants, 50, seemed about right, large enough to provide a diversity of scientific interests and small enough to allow for in-depth scientific discussions.

The journal Classical and Quantum Gravity (which is the leading journal in relativistic astrophysics) will publish a feature issue with articles based on selected presentations at the workshop.

At the workshop, advances in a number of areas were reported:

- **Equation of state of dense matter.** From the discussions, and as a result of the improved understanding of low-density atom gases in recent years, it became clear that the nuclear equation of state at densities up to around that of atomic nuclei can be much more tightly constrained. This will reduce significantly the uncertainties in predictions of some astrophysical phenomena. Another advance was in predicting the properties of hot dense matter at subnuclear densities. Here it has been found that the abundance of light nuclei is larger than predicted in earlier work.

- **Neutrino interactions.** Neutrino interactions in dense matter are affected significantly by nucleon–nucleon interactions. Thanks to ideas developed in nuclear theory based on the renormalization group and chiral effective field theories, it is now possible to calculate interaction effects more simply that was previously possible.

- **Efficient approximations of neutrino effects.** Present fully general-relativistic simulations of stellar collapse and compact binary coalescence do not yet include microphysical details and radiation transport of neutrinos at the level necessary to make astrophysical predictions. At the workshop there was lively and fruitful discussion on various approaches that would allow the computationally efficient inclusion of microscopic physics and approximate schemes for neutrino transport and interactions in near-future multi-dimensional simulations. Multiple new collaborations on these aspects were formed.

Assessment of the results and impact of the event on the future direction of the field

The workshop promises to have strong impact on the future development of the field. At a basic level, it brought together people from different communities in an environment that stimulated exchange of information and ideas, and which thereby had a "community-building" function. In addition, it played a role in nurturing the younger scientists who will carry the field further in the years to come.

The responses of participants to the questionnaire sent out after the workshop indicates that many participants got new ideas or initiated collaborations at the workshop. Already one can point to a number of areas where the workshop appears to be having a significant impact on the future development of the field:

- **Equation of state of dense matter.** A collaboration was begun to more tightly pin down the properties of neutron matter at subnuclear densities. One may expect that this will lead to an improved understanding of the crust of neutron stars. In the future, the recent advances in nuclear theory should make it possible to develop improved nucleon–nucleon interactions also for neutron–proton interactions.

- **Neutrino–matter interactions and efficient approximations.** At the workshop, there was extensive collaboration between people making calculations of basic physical processes with those performing astrophysical modelling of stellar collapse and related phenomena. This collaboration will continue in the future, and it will lead to improvements in the quality of the rates of processes involving neutrinos in dense matter. At the workshop there was extensive discussion of simplified schemes for treating neutrino transport. One can expect that such methods will become important in the future in modelling situations that are impossible computationally if the full transport problem has to be solved in detail.

- **Modular programming and open input physics.** A considerable number of participants voiced there interest in community-wide open physics modules for codes that would facilitate easy comparison of numerical schemes and would lower the bar to entering the field from the outside.

Key contributions (primarily new results presented in the shorter topical talks) will be published in a refereed topical volume of Classical and Quantum Gravity (CQG). CQG is the world leading journal for topics involving general relativity and among the leaders in relativistic astrophysics. These CQG articles will add lasting value to the workshop's impact.

Programme

Monday, 24 August

8.30 Registration
9.30 Welcome and introduction of participants

10.00 **Core Collapse Supernova Simulations**
Convenor: J. M. Lattimer
Adam Burrows, The emerging synthesis in core-collapse supernova theory
Jeremiah Murphy, Critical conditions for successful neutrino-driven explosions and a model for gravitational wave emission
Simon Scheidegger, 3D MHD core collapse simulations: recent insights from the Basel group
Irina Sagert, Signals of the QCD phase transition in core-collapse supernovae
Martin Obergaulinger, Simulating the magneto-rotational instability in core-collapse supernovae
Evan O'Connor, Black hole formation in failing core-collapse supernovae

13.00 Lunch

14.30 **High-Density Equation of State**
Convenor: C. J. Pethick
James Lattimer, Overview: The equation of state for numerical simulations
Yeunhwan Lim, Finite range Thomas Fermi model
Micaela Oertel, QCD phase diagram and quark matter at high densities
Ken'ichiro Nakazato, Exploring hadron physics in black hole formation: a new promising target of neutrino astronomy
Francesco Pederiva, A density-dependent nucleon-nucleon interaction for the high-density equation of state
Evan O'Connor, Low-density nuclear matter in supernovae

17.00 Reception

Tuesday, 25 August 2009

9.30 **Neutrino-Matter Interactions**
Convenor: S. Hannestad
Achim Schwenk, Overview: Neutrino-matter Interactions from chiral effective field theory
Anthea Fantina, Type II supernovae: Impact of electro-weak processes during core-collapse phase
Albino Perego, Mu and tau neutrinos in supernova simulations (and a leakage scheme)
Steen Hannestad, Collective neutrino flavor oscillations in dense matter
Tina Lund, Detecting supernova neutrinos with IceCube

12:30 Lunch

14.00 Discussion, brain-storming and collaboration

Wednesday, 26 August 2009

9:30 **Merging Compact Binaries and Single Neutron Stars**
Convenor: S. Rosswog
Stephan Rosswog, Overview: Collisions of white dwarfs as a new progenitor channel for type Ia supernovae
Ernazar Abdikamalov, Accretion-induced collapse of white dwarfs
Enrique Moreno-Mendez, Binaries, gamma-ray bursts and hypercritical accretion
Masaru Shibata, Numerical simulations for binary merger in Japan
Matt Duez, New steps towards realistic simulations of general black hole-neutron star mergers
David Neilsen, Neutron star binaries, magnetic fields, and equations of state
Luciano Rezzolla, Simulations of binary neutron stars: results, difficulties and prospects
Giovanni Corvino, Bar-mode instability of differentially rotating neutron stars with realistic equations of state

12.30 Lunch

13.30 **Gravity, Hydrodynamics and Magnetohydrodynamics**
Convenor: J. M. Ibanez
W. David Arnett, Turbulence, rotation and MHD: the von Neumann approach
Stephan Rosswog, Relativistic smooth particle hydrodynamics from a variational principle
Jerome Novak, Solving the Einstein equations: why bother about the constraints?
Pablo Cerda-Duran, General relativistic hydrodynamics beyond bouncing polytropes

16.00 Excursion to the Louisiana Museum of Modern Art, Humlebæk, with barbecue

Thursday, 27 August 2009

9.30 **Methods: Transport and Approximations / Gravity, HD, MHD**
Convenor: C. D. Ott
Aake Nordlund, Overview: Optimized radiative transfer
Peter Diener, Automatic code generation
Ian Hawke, Numerical simulations of relativistic multifluids
Erik Schnetter, Computational Infrastructure
Adam Burrows, Microphysics, methods, and core-collapse supernovae
Simon Scheidegger, The isotropic diffusion source approximation
Yuichiro Sekiguchi, Full GR Simulations with microphysics
Kenta Kiuchi, General relativistic equilibrium configurations with purely toroidal fields and its stability

13.00 Lunch

14.00 Discussion, brain storming and collaboration

Friday, 28 August 2009

9.30 **Nuclei and the Outer Layers of Neutron Stars**
Convenor: K. Langanke
Karlheinz Langanke, Overview: Electron capture rates and neutrino-nucleus cross sections
Almudena Arcones, I. Nuclear statistical equilibrium and beta equilibrium
II. Nucleosynthesis in Neutrino-driven winds
Nikolaj Zinner, Fission and the r-process
Ken'ichiro Nakazato, Gyroid phase in nuclear pasta
Alexander Potekhin, Overview: Neutron star envelopes: (micro)physics and thermal radiation
Wynn Ho, Atoms and atmospheres in strong magnetic fields

13.00 Lunch

14.30 **Closing session**
Convenor: C. D. Ott

Microphysics in Computational Relativistic Astrophysics: MICRA2009

List of registrants

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