Titles and Abstracts

Close black hole encounters and non-merging ringdowns

Gungwon Kang
Chung-Ang University

A perturbed black hole produces characteristic radiations whose frequencies possess some physical information of the black hole such as its mass and angular momentum. We have investigated close hyperbolic encounters of two black holes. In addition to the single burst signal associated with the hyperbolic passage, a non-merging ringdown gravitational radiation has been found for the first time. This new type of gravitational waveforms turns out to be due to the tidal deformations of individual constituent black holes through strong gravitational interactions. We briefly report the main results of this phenomenon, and discuss implications on astrophysical observability and testing horizon dynamics in black hole scattering.

Vacuum axisymmetric gravitational collapse, revisited

Andrzej Rostworowski
Jagiellonian University

I will discuss my efforts to reproduce the results of the renown Abrahams&Evans (AE) paper on a critical axisymmetric gravitational collapse [Abrahams&Evans, PRL70 2980 (1993)]. There were some such tries in the past but, as far as I know, no one has really succeeded so far. In particular, I will discuss AE ansatz, its linearized approximation, the initial data choice and the bases of the pseudospectral code that I have constructed. I will also try to briefly summarize the efforts undertaken in the last 30 years to repeat AE results and check their conclusions.

Perturbation of Electromagnetic Waves and Motions of Charged Particles

Chan Park
Institute for Gravitational Wave Astronomy, Henan Academy of Sciences

Electromagnetic waves (EMWs) are currently a crucial tool in gravitational wave (GW) observation. Both interferometric GW detectors and pulsar timing arrays observe GWs by measuring perturbations in EMWs. However, these methods are based on geometric optics, which is valid only when the frequency of GWs is much smaller than that of EMWs. Focusing on the fact that EMWs fundamentally represent EM fields, we directly address perturbations in EMWs by obtaining perturbed solutions of Maxwell's equations. To measure the perturbed EMWs, we consider a charge moving within the EMW. A charge moving in a plane EMW has constants of motion, and we analytically derive the perturbations in these constants, discussing the potential of a new method for GW detection based on these findings.

A discrete de Rham scheme for the exterior calculus Einstein's equations

JiaJia Qian
Monash University

Applying new numerical techniques to the Einstein's equations is always a challenge due to the complexity and nonlinearity of these equations. In this talk, we propose a discrete de Rham (DDR) scheme for a 3+1 exterior calculus formulation of Einstein's equations. The DDR method works on general polytopal meshes and has an arbitrary order of convergence, as well as reproducing certain aspects of the continuous de Rham complex. For the Maxwell's equations, these properties are enough to achieve a discrete preservation of constraint by reproducing the continuous calculations. For Einstein's equations however, we can preserve certain constraints on the tetrad, but the preservation of the Hamiltonian constraint remains elusive. We present numerical results for two schemes; one based on the simplest coherent set of equations, and the other related to a formulation that we have proved to be well-posed.

Periodic solutions for simple Hamiltonian PDEs

Maciej Maliborski
University of Vienna

To better understand the dynamics of asymptotically anti-de Sitter (AdS) spacetimes and the crucial role of time-periodic solutions, we examine simplified models. In this talk, I will present a study of a toy-model Hamiltonian partial differential equation defined on a bounded domain. I will discuss our latest results, highlighting the intricate structure of time-periodic solutions and their implications for the broader question of stability of AdS. This is joint work with Filip Ficek.

Evolution of bare quark stars in numerical relativity

Enping Zhou
Huazhong University of Science and Technolog

Based on the Witten's Conjecture, i.e., 3-flavor quark matter might be the stable state of dense matter, it is believed that at least part of the conventional 'neutron stars' are actually quark stars, if not all of them. Unlike neutron stars, the surface density of quark stars are extremely large (and hence they are called bare quark stars) and comparable to nuclear saturation density. Such finite surface density results in difficulties to model the them numerically. Nevertheless, it is essential to model processes such as the merger of quark stars in order to understand the differences between them and binary neutron star mergers and to distinguish them by observations. In this talk, I will introduce our attempts to model bare quark stars in numerical relativity by modifying the primitive recovery procedure accordingly. I will also introduce the differences between binary quark star merger and binary neutron star merger we found, in the collapse behavior and matter ejections during the post-merger phase.

Cauchy-characteristic matching

Sizheng Ma
Perimeter Institute

Cauchy-characteristic matching is a novel numerical-relativity technique that enables the evolution of Einstein's equations on an effectively infinite computational domain. In this talk, I will present our recent successful applications of this method to binary black hole mergers, and demonstrate its transformative potential for modeling tail and memory effects in eccentric binaries. I will also discuss my latest work on extending Cauchy-characteristic extraction (and matching) to theories beyond General Relativity.

FEEC IN FLOW

Ralf Hiptmair
ETH Zurich

Speaker: R. HIPTMAIR (Seminar for Applied Mathematics, ETH Zürich, joint work with H. Heumann, C. Pagliantini, and W. Tonnon)

I am going to review mesh-based Eulerian and Lagrangian discretizations of transient and stationary advection-diffusion boundary value problems (BVPs) for differential forms. Advection is passive, assuming the underlying velocity vector field to be given and sufficiently regular.
Though this subject has been exhaustively studied for 0-forms, the development of numerical methods for higher degrees started only 15 years ago, guided by the principle that numerical methods designed for the case of 0-forms can usually be generalized to ℓ-forms with suitable adaptations. As in the case of 0-forms the main challenge is stabilization by taking into account the direction of the flow.
The Eulerian methods start from (localized) standard variational formulations of the advection-diffusion BVP, restrict them to conforming or broken (in the case of discontinuous Galerkin (DG) methods) trial and test spaces, and add stabilization terms. Such stabilized Galerkin methods come in various flavors: upwind DG, Galerkin least squares, conforming interior penalty, upwind projection, to name some of them. The Lagrangian methods directly discretize the material derivative by tracking the flow. We discuss semi-Lagrangian discretizations on a fixed mesh and will give a glimpse of their application to non-linear transport.
References:
[1] H. HEUMANN AND R. HIPTMAIR, Convergence of lowest order semi-Lagrangian schemes, Foundations of Computational Mathematics, 13 (2013), pp. 187–220.
[2] H. HEUMANN AND R. HIPTMAIR, Stabilized Galerkin methods for magnetic advection, ESAIM Math. Model. Numer. Anal., 47 (2013), pp. 1713–1732.
[3] H. HEUMANN , R. HIPTMAIR , K. L I , AND J. XU, Fully discrete semi-Lagrangian methods for advection of differential forms, BIT Numerical Mathematics, 52 (2012), pp. 981–1007.
[4] H. HEUMANN , R. HIPTMAIR , AND C. PAGLIANTINI, Stabilized Galerkin for transient advection of differential forms, Discrete and Continuous Dynamical Systems - Series S, 9 (2016), pp. 185–214.
[5] R. HIPTMAIR AND C. PAGLIANTINI, Splitting-based structure preserving discretizations for magnetohydrodynamics, SMAI J. Comput. Math., 4 (2018), pp. 225–257.
[6] W. TONNON AND R. HIPTMAIR, Semi-Lagrangian finite element exterior calculus for

incompressible flows, Adv. Comput. Math., 50 (2024), pp. Paper No. 11, 29.

Dynamics of black hole horizons in binary black hole mergers

Badri Krishnan
Radboud University, Nijmegen, The Netherlands

Marginally trapped surfaces (MTSs) have been used fruitfully to understand properties of black holes in binary black hole mergers. This includes: i) measurements of mass, spin and multipole moments, ii) energy fluxes across the horizons and correlations with gravitational waveforms, iii) a detailed understanding of how two MTSs merge to yield a single remnant MTS. In this talk I will review some recent results in these directions.

Stationary and time dependent solutions of the axially symmetric Einstein-Vlasov system.

Håkan Andreasson
University of Gothenburg

In this talk I will present a numerical method used to obtain axially symmetric stationary solutions of the Einstein-Vlasov system. It is based on a mass-preserving algorithm which has been used successfully to construct a wide range of stationary solutions. Recently it was shown that this algorithm converges in a simple case. A few numerical results and open problems will be discussed, in particular those that are related to highly compact solutions. I will also consider the evolution problem and discuss methods such as the particle in cell method and the finite volume method. A few examples related to the weak cosmic censorship conjecture and the Hoop conjecture will be shown.

Quasi-Local Mass in a Binary Black Hole Merger

Daniel Pook-Kolb
Max Planck Institute for Gravitational Physics/Leibniz University Hannover

One of the major open problems in classical general relativity is how one should define the mass of a finite region of space. In this talk, we will investigate a promising definition proposed by Wang and Yau in 2009. A closed 2-surface bounding the region of interest is embedded isometrically into Minkowski space. The mass is then calculated by comparing the extrinsic geometries. The Wang-Yau mass has many desirable properties, but it has previously not been calculated for surfaces in dynamical spacetimes. To remedy this, we will discuss how the Wang-Yau mass can be computed in practice in numerical simulations and also extend the original definition to surfaces important in black hole dynamics: their quasi-local horizons. Finally, we look at how this mass behaves in a merger of black holes.

A global approach to the nonlinear perturbation of a black hole by gravitational waves

Jörg Frauendiener
University of Otago

It is well known that gravitational waves interact in a non-linear way. This makes it difficult to describe them rigorously. The cleanest description is based on certain conformal properties of the Einstein equations — first discovered by R. Penrose they were rigorously developed and used by H. Friedrich to prove several important global results for general relativistic space-times. The conformal field equations which implement this conformal framework provide various well-posed initial (boundary) value problems for use in many different situations. The talk will give a computational perspective on one particular application, the non-linear interaction of gravitational waves with an initially static (and spherically symmetric) black hole. We will show how to 'kick' the black hole and possibly how to spin it up.

On the convergence of the discontinuous Galerkin scheme for Einstein-scalar equations

Yuewen Chen
Tsinghua University

We prove the stability and convergence of the high order discontinuous Galerkin scheme to spherically symmetric Einstein-scalar equations for a class of large initial data that ensures the formation of a black hole. Having chosen the Bondi coordinate system, we achieve L^2 stability and obtain the optimal error estimates. This is a collaborative work with Professor Chi-Wang Shu and Professor Shing-Tung Yau.

Critical collapse simulations with bamps

Daniela Cors
University of Cambridge

Reliable numerical simulations require a thorough control of all non-physical dynamics that can appear, such as constraint violations and coordinate singularities. These become more challenging in the strong-field regime and particularly near the threshold of collapse, where, in the absence of a horizon, arbitrarily large curvatures cannot be excised. At this threshold, a regular and universal structure emerges in spherical symmetry, referred to as critical phenomena. Beyond sphericity, the picture of critical collapse is unclear. Clarification demands simulations that are closer to the threshold. To that end, we have proposed formulation improvements for critical collapse simulations. In this talk I will present a modified generalised-harmonic damping scheme and a self-similarity compatible gauge designed to tune closer to the threshold. I will also show what we have been able to learn about criticality beyond spherical symmetry thanks to these improvements.

Computation meets gravitation: from anti-de Sitter to de Sitter

Yu Tian
University of Chinese Academy of Sciences

Dynamics related to gravity and its applications, including but not limited to gravitational waves, are important in various fields in theoretical physics, which inevitably need numerics. This talk will focus on the formalisms and applications of numerical relativity in asymptotic anti-de Sitter space-times (related to AdS/CFT) and asymptotic de Sitter space-times.

Apparent horizon finders for 3D numerical spacetimes

Lap Ming Lin
The Chinese University of Hong Kong

Apparent horizon is an important concept for characterizing the existence and properties of black holes in numerical spacetimes. Apparent horizon finders for generic 3D spacetimes have been developed using different techniques. In this talk, we shall give a brief review of the topic and present our latest apparent horizon finder based on the multigrid method. Our finder has been tested with both analytic and numerical data, including dynamically inspiraling binary black hole spacetimes. Our multigrid-based finder performs comparably to AHFinderDirect, the current fastest open-source finder, in terms of accuracy and starts to outperform it at high angular resolutions in terms of speed. This suggests that the multigrid algorithm provides an alternative option for studying apparent horizons, especially when high resolutions are needed.

Differential complexes and compatible finite elements with applications to relativity

Kaibo Hu
The University of Edinburgh

Differential complexes are sequences of spaces connected by differential operators. In this talk, we discuss differential complexes of tensors (hyperforms), generalizing the de Rham sequences and encoding differential structures of tensor-valued problems from continuum mechanics, differential geometry and general relativity etc. Associated with each complex, various PDE problems are formulated, such as the Hodge Laplacian, Hodge Dirac and Hodge wave problems. We discuss possibilities of reformulating the linearized Einstein equations in these forms.
The Finite Element Exterior Calculus (FEEC) provides a framework for discretizing formulations based on complexes. In particular, the de Rham complex enjoys a canonical finite element discretization, unified as finite element differential forms. We review the construction and discuss process in discretizing tensor-valued spaces and complexes.

Hyperboloidal evolution, or how to smoothly reach (future null) infinity

Alex Vañó Viñuales
University of Lisbon

Gravitational wave radiation is only unambiguously defined at future null infinity, the collection of the end-points of future-directed null geodesics. A convenient way to reach null infinity in numerical relativity simulations is via hyperboloidal foliations: smooth spacelike slices suitable for solving the Einstein equations as an initial value problem. Spatial compactification on a hyperboloidal slice ensures that future null infinity is included in the numerical integration domain at finite coordinate distance. However, it also requires a regularization of the Einstein equations, and how this is achieved gives rise to different approaches to hyperboloidal evolution. I will give an overview of past and present implementations of the hyperboloidal method to general relativity, putting special emphasis on those being actively developed, as well as report on current progress.