# 9th Central European Relativity Seminar

February 14-16, 2018, Kraków

## Schedule

### Thursday, 14 February

*Chair: TBU*

14:00-15:00 **Andrzej Staruszkiewicz** (Jagiellonian University) – *Physical Relevance of the Lorentz group*

15:00-15:30 Coffee break

15:30-15:50 **Filip Ficek** (Jagiellonian University) – *Schrödinger-Newton-Hooke equation*

15:50-16:10 **Oliver Rinne** (HTW Berlin) – *A geometric flow approach to the static metric extension problem for the Einstein equations in axisymmetry*

16:10-16:30 **Julius Serbenta** (CFT PAN) – *Probing the matter content of the spacetime using parallax*

16:30-17:00 Coffee break

17:00-17:20 **Michele Grasso** (CFT PAN) – *Ray tracing, parallax, position and redshift drift in numerical relativity*

17:20-17:40 **Zoe Wyatt** (University of Edinburgh & University of Vienna) – *Attractors of the Einstein-Klein-Gordon system*

17:40-18:00 **Léo Bigorgne** (Université Paris-sud) – *Asymptotics properties of the small data solutions of the Vlasov-Maxwell system*

### Friday, 15 February

*Chair: TBU*

9:00-10:00 **Martin Taylor** (Princeton University) – *The nonlinear stability of the Schwarzschild family of black holes*

10:00-10:30 Coffee break

10:30-10:50 **Gernot Heißel** (University of Vienna) – *Kantowski-Sachs cosmology with Vlasov matter*

10:50-11:10 **Andrzej Rostworowski** (Jagiellonian University) – *Cosmological perturbations in Regge-Wheeler formalism*

11:10-11:30 **Mieszko Rutkowski** (Jagiellonian University) – *Nonlinear perturbation theory of the Reissner-Nordström black hole*

11:30-11:50 **Armando Cabrera Pacheco** (University of Tübingen) – *On the stability of the positive mass theorem for asymptotically hyperbolic graphs*

11:50-14:00 Lunch break

*Chair: TBU*

14:00-14:20 **Georgios Doulis** (University of Warsaw ) – *A new method for generating binary black hole initial data*

14:20-14:40 **Jarrod Williams** (Erwin Schrödinger Institute) – *Constructing initial data with partially-prescribed electric and magnetic Weyl curvatures*

14:40-15:00 **Dominika Hunik-Kostyra** (Jagiellonian University) – *Conformal flow on $S^3$*

15:00-15:30 Poster session and coffee break

*Chair: TBU*

15:30-15:50 **Diego Carranza Ortiz** (Queen Mary University of London) – *Construction of adS-like spacetimes: the tracefree matter case*

15:50-16:10 **Remigiusz Durka** (Universtity of Wrocław) – *NUT charge as a rotation*

16:10-16:30 **Tomasz Smołka** (KMMF, Uniwersytet Warszawski) – *Electromagnetic and gravitational Hopfions*

## Saturday, 16 February

*Chair: TBU*

9:00-9:40 **Gernot Neugebauer** (Friedrich-Schiller-Universität Jena) – *Non-existence of vacuum axisymmetric black holes with non-connected horizons*

9:40-10:10 Coffee break

10:10-10:30 **Camilo Posada** (Silesian University in Opava) – *Slowly rotating ultra-compact Schwarzschild stars*

10:30-10:50 **Wojciech Kulczycki** (Jagiellonian University) – *Mass and angular velocity in general-relativistic Keplerian disks around black holes*

10:50-11:10 **Jan Głowacki** (Radboud University) – *Groupoid approach to the symmetries of the Einstein's equation as a potential framework for the quantization*

11:10-11:40 Coffee break

11:40-12:00 **Tomasz Miller** (Jagiellonian University) – *On the causal evolution of $N$-particle systems*

12:00-12:20 **Alexander Zhidenko** (Universidade Federal do ABC (UFABC)) – *Echoes of compact objects: new physics near the surface and matter at a distance*

12:20-12:40 **Andras Laszlo** (Wigner Research Centre for Physics) – *GR experiment with spin polarized particle beams*

# Abstracts

## Posters

### On the asymptotics of solutions to the evolutionary form of the constraints

*Károly Csukás, Wigner RCP, Hungary, csukas.karoly@wigner.mta.hu*

Recently in a series of papers [1, 2, 3, 4] István Rácz introduced a novel approach to solve the constraint equations. Interpreting the constraints either as a parabolic-hyperbolic or a strongly hyperbolic system makes it possible to solve them as evolutionary equations. It is of fundamental importance to know if initial conditions can be chosen such that the solutions are guaranteed to be asymptotically flat. In both evolutionary settings results relevant for near Schwarzschild initializations will be presented.

Joint work with István Rácz, supported by CA16104 COST Grant.

# References

[1] I. Rácz, *Cauchy problem as a two-surface based 'geometrodynamics'*, Class. Quant. Grav. **32** (2015) 015006 doi:10.1088/0264-9381/32/1/015006 [arXiv:1409.4914 [gr-qc]].

[2] I. Rácz and J. Winicour, *Black hole initial data without elliptic equations*, Phys. Rev. D **91** (2015) no.12, 124013 doi:10.1103/PhysRevD.91.124013 [arXiv:1502.06884 [gr-qc]].

[3] I. Rácz, *Constraints as evolutionary systems*, Class. Quant. Grav. **33** (2016) no.1, 015014 doi:10.1088/0264-9381/33/1/015014 [arXiv:1508.01810 [gr-qc]].

[4] I. Rácz and J. Winicour, *Toward computing gravitational initial data without elliptic solvers*, Class. Quant. Grav. **35** (2018) no.13, 135002 doi:10.1088/1361-6382/aac5c5 [arXiv:1712.03294 [gr-qc]].

### How to localize energy in classical field theory

*Marian Wiatr, Uniwersytet Warszawski, m.wiatr@student.uw.edu.pl*

Imposing appropriate boundary conditions, field evolution within a bounded region V becomes an isolated Hamiltonian system (in the strong, functional-analytic sense). The value of its Hamiltonian function is identified with the (quasi-local) field energy contained in $V$. The goal of this approach is to clarify the notion of the quasi-local gravitational field energy.

## Talks

### Asymptotics properties of the small data solutions of the Vlasov-Maxwell system

*Léo Bigorgne, Université Paris-sud, leo.bigorgne@u-psud.fr*

The Vlasov-Maxwell system is a classical model in plasma physics. Glassey and Strauss proved global existence for the small data solutions of this system under a compact support assumption on the initial data. We will present how vector field methods can be applied to revisit this problem. In particular, it allows to remove all compact support assumptions on the initial data and obtain sharp asymptotics on the solutions. We will also discuss the null structure of the system which constitutes a crucial element of the proof.

### On the stability of the positive mass theorem for asymptotically hyperbolic graphs

*Armando Cabrera Pacheco, University of Tübingen,*
*cabrera@math.uni-tuebingen.de*

The rigidity of the Riemannian positive mass theorem asserts that the ADM mass of an asymptotically flat manifold with non-negative scalar curvature equals zero if and only if the manifold is the Euclidean space. It is natural to ask: if the ADM mass of a given manifold is close to zero, is the manifold close to the Euclidean space in some sense? Huang and Lee proved the stability (in the sense of currents) of the positive mass theorem for asymptotically flat graphs. We will describe how to use results of Dahl, Gicquaud and Sakovich to adapt Huang and Lee's ideas to obtain a stability result for positive mass theorem for asymptotically hyperbolic graphs.

### Construction of adS-like spacetimes: the tracefree matter case

*Diego Carranza Ortiz, Queen Mary University of London,*
*d.a.carranzaortiz@qmul.ac.uk*

In this talk I will present a systematic procedure for the construction of solutions to the Einstein equations with negative cosmological constant coupled to a tracefree matter field. The construction is based on the conformal Einstein field equations, from which a system of wave equations for the relevant fields is obtained. Exploiting the coordinate and conformal gauge freedom, as well as providing suitable initial and boundary data, local existence and uniqueness of a solution is proved. I will briefly discuss some particular cases of interest such as the Maxwell and conformally invariant scalar fields.

### A new method for generating binary black hole initial data

*Georgios Doulis, University of Warsaw , gdoulis@phys.uoa.gr*

We present a novel implicit numerical scheme for solving the constraints of general relativity in their parabolic-hyperbolic form. The importance of studying the constraints in a non-elliptic setting stems from the possibility that the "junk radiation", common to all elliptic formulations of the constraints, could be avoided. The proposed method is unconditionally stable and has the great advantage that it does not require the imposition of any boundary conditions near the black holes. The new implicit solver is used to construct initial data for distorted and binary black hole configurations. This work was supported by a STSM Grant from COST Action CA16104: Gravitational waves, black holes and fundamental physics (GWverse).

### NUT charge as a rotation

*Remigiusz Durka, Universtity of Wrocław, remigiusz.durka@uwr.edu.pl*

I offer new approach to the subject of Taub-NUT space-time supposedly possessing gravitational analog of the magnetic monopole. Realizing that the source of many inconsistencies lies in neglecting the effects of the wire singularities present in this solution, I am able to explain NUT charge by the means of quite peculiar rotation. Among many things, this allows for establishing the consistent description of the black hole thermodynamics for the Lorentzian Taub-NUT spacetime with essential contribution from the wire singularities to the angular momentum and the total entropy.

### Schrödinger-Newton-Hooke equation

*Filip Ficek, Jagiellonian University, filip.ficek@uj.edu.pl*

I will present how the Schrödinger-Newton equation with a harmonic term, previously known from atomic physics (it describes self-gravitating boson gas in a harmonic trap), can be obtained as a non-relativistic limit of AdS perturbations. I will also present some properties of its solution.

### Ray tracing, parallax, position and redshift drift in numerical relativity

*Michele Grasso, CFT PAN, grasso@cft.edu.pl*

I will present a numerical approach to the problem of evaluating the parallax, position drift (proper motion) and redshift drift (secular change of the redshift) of faraway sources in numerical relativity. The mathematical machinery is based on the covariant formulation of the geometric optics and the bilocal geodesic operators and their relation to the geodesic deviation equation and curvature. The formalism is applicable to any spacetime, but is specifically meant to work in numerical cosmology.

### Groupoid approach to the symmetries of the Einstein's equation as a potential framework for the quantization

*Jan Głowacki, Radboud University, j.glowacki@student.ru.nl*

The starting point of our talk is the paper by Christian Blohmann, Marco Cezar Barbosa Fernandes and Alan Weinstein "Groupoid symmetry and constraints in General Relativity". The authors described the diffeological groupoid which captures symmetries of the Einstein's equation seen as an evolution problem. Furthermore, they argue that the bracket structure of the Lie algebroid associated to this groupoid matches the Poisson bracket structure on the constraints that appear in the hamiltonian formulation of the equation. In the talk we will revise this perspective and explain how it might be used as a starting point to the canonical quantization. We will start by giving some simple examples to support the claim that groupoids and algebroids provide an elegant and powerful language to capture symmetries of physical theories and may be used in the context of quantization. Next, we will advertise the use of diffeological spaces, which provide an elegant way to deal with the groupoid in question, as an alternative to the widely used manifold framework. Finally, we will briefly describe the groupoid that captures the symmetries of the Einstein's equation in hamiltonian formulation, pointing out the possibilities of carrying out further research in the direction of quantization.

### Kantowski-Sachs cosmology with Vlasov matter

*Gernot Heißel, University of Vienna, gernot.heissel@univie.ac.at*

We analyse the Kantowski-Sachs cosmologies with Vlasov matter of massive and massless particles using dynamical systems analysis. We show that generic solutions are past and future asymptotic to the non-flat locally rotationally symmetric Kasner vacuum solution. Furthermore, we establish that solutions with massive Vlasov matter behave like solutions with massless Vlasov matter towards the singularities.

### Conformal flow on $S^3$

*Dominika Hunik-Kostyra, Jagiellonian University, hunik.dominika@gmail.com*

I will present an infinite-dimensional dynamical system called the conformal flow. It accurately approximates the conformally invariant cubic wave equation on the Einstein cylinder $\mathbb{R} \times \mathbb{S}^3$ for small rotationally symmetric initial data in the weak-field regime. The problem is related to a self-interacting conformally coupled scalar in four-dimensional anti-de Sitter spacetime by a conformal transformation. I will briefly discuss the most remarkable features of the conformal flow, such as existence of low-dimensional invariant subspaces and stationary states, for which energy does not flow between the modes.

### Mass and angular velocity in general-relativistic Keplerian disks around black holes

*Wojciech Kulczycki, Jagiellonian University,*
*wojciech.kulczycki@doctoral.uj.edu.pl*

In my talk I consider self-gravitating toroidal disks around black holes that rotate according to the general-relativistic Keplerian rotation law. I investigate the problem of the existance of inequalities that could be used to estimate masses of such systems. The obtained bounds have a form of expressions containing quantities connected to the angular velocity of the particles in the disk. The numerical data fit these results.

### GR experiment with spin polarized particle beams

*Andras Laszlo, Wigner Research Centre for Physics,*
*laszlo.andras@wigner.ma.hu*

In a recent series of papers by Morishima et al, it was argued that the gravitational field of the Earth gives a systematic GR contribution to muon magnetic moment anomaly (g-2) experiments. In this talk we show that the pertinent contribution to g-2 experiments happens to be negligible, however, GR gives a sizeable contribution to other type of spin polarized particle beam experiments. For instance, the electric dipole moment (EDM) search experiments for charged particles are conducted via so called frozen-spin storage rings. Recently, in CQG35(2018)175003 we showed that in a frozen-spin storage ring, the Earth's gravitational field shall give a substantial GR contribution to the EDM observable. Thus frozen-spin rings can be used as GR experiments which test the tensorial nature of GR at a microscopic level. The JEDI Collaboration, which was originally founded as an R&D collaboration for developing frozen-spin (EDM) rings, adopted this GR experimental proposal into their physics programme. It seems thus, that the frozen-spin (EDM) ring experiments can become also interesting for the GR community.

### On the causal evolution of $N$-particle systems

*Tomasz Miller, Jagiellonian University, tomasz.miller@uj.edu.pl*

In a series of papers written jointly with M. Eckstein, we have proposed and developed a natural extension of the standard causal precedence relation $J^+$ onto the space $\mathscr{P}(\mathcal{M})$ of all Borel probability measures on a given spacetime $\mathcal{M}$. Using the tools from the optimal transport theory, one can utilize thus obtained notion of 'causality between measures' to model a causal time-evolution of a spatially distributed physical entity in a globally hyperbolic spacetime. In my talk, after briefly presenting the above mentioned extension of $J^+$ and explaining what it means for a measure to evolve causally, I will discuss how this formalism can be extended to encompass many-particle systems. This in particular requires generalizing several definitions and facts from basic causality theory into a broader, '$N$-particle' setting.

### Non-existence of vacuum axisymmetric black holes with non-connected horizons

*Gernot Neugebauer, Friedrich-Schiller-Universität Jena,*
*Gernot.Neugebauer@uni-jena.de*

We resume discussions of the question, whether the spin-spin repulsion and the gravitational attraction of two aligned black holes can balance each other. Based on the discussion of a boundary problem for non-connected (Killing) horizons and the resulting violation of characteristic black hole properties, we present a non- existence proof for the equilibrium configuration in question. From a mathematical point of view, our result is a further example for the efficiency of the inverse ("scattering") method in nonlinear theories. Ideas concerning extensions of the proof will be sketched.

### Slowly rotating ultra-compact Schwarzschild stars

*Camilo Posada, Silesian University in Opava, camoposada82@gmail.com*

In this talk I will review the Schwarzschild interior solution, or 'Schwarzschild star', and its connection with gravastars. It is well known that the Schwarzschild star shows a divergence in pressure when the radius of the star reaches the

Buchdahl limit. Mazur and Mottola showed that this divergence is integrable, inducing non-isotropic transverse stresses on a surface of some radius $R_0$. In the ultra-compact limit, when $R_0$ approaches the Schwarzschild radius, the interior solution becomes one with negative pressure and no event horizon, which resembles a gravastar. Recently, it was shown that this model can be extended to slow rotation using the equations derived by Hartle for slowly rotating relativistic masses. I will discuss these results, and their relevance in the context of the I-Q relations.

### A geometric flow approach to the static metric extension problem for the Einstein equations in axisymmetry

*Oliver Rinne, HTW Berlin, oliver.rinne@htw-berlin.de*

Metric extension problems for the static Einstein equations with prescribed geometric data on an inner boundary 2-surface arise in the context of Bartnik's proposal of a quasi-local mass in general relativity. The aim of this project is to construct such extensions numerically. We restrict ourselves to axisymmetry for simplicity. Working in Weyl coordinates, we develop a geometric flow that moves an initial guess for the boundary surface towards a surface satisfying the desired boundary conditions. We test the numerical method both for Bartnik data arising from known static axisymmetric vacuum spacetimes and for perturbed data. This is joint work with Carla Cederbaum and Markus Strehlau.

### Cosmological perturbations in Regge-Wheeler formalism

*Andrzej Rostworowski, Jagiellonian University, arostwor@th.if.uj.edu.pl*

The standard framework for studying cosmological perturbations is based on "1+3" decomposition of metric perturbations, resulting in scalar-vector-tensor sectors of perturbations. The standard framework for studying black hole perturbations(Regge-Wheeler formalism) is based on "2+2" decomposition of metric perturbations resulting in polar and axial sectors of perturbations (after expansion into suitable polar/axial spherical harmonics). I will use the later in the context of linear perturbations of FLRW model, in particular I will show how the general solution of perturbation equations can be constructed from the solution of a scalar wave equation on FLRW background. In view of the recent work [PRD96, 124026 (2017)], this is a promising result in the context of nonlinear cosmological perturbations (see also Mieszko Rutkowski's talk at this meeting).

### Nonlinear perturbation theory of the Reissner-Nordström black hole

*Mieszko Rutkowski, Jagiellonian University, mieszkorutkowski24@gmail.com*

In my talk I will present a nonlinear perturbation theory of a Reissner-Nordström black hole. I will show that, at each perturbative level, Einstein-Maxwell equations can be reduced to four inhomogeneous wave equations, two for polar and two for axial sector. Gravitational part of these equations is similar to Regge-Wheeler and Zerilli equations with source and additional coupling to the electromagnetic sector.

### Probing the matter content of the spacetime using parallax

*Julius Serbenta, CFT PAN, julius@cft.edu.pl*

We present a new formulation of geometric optics in general relativity. Consider a measurement of light emission from a point source in a distant region. The observation is performed by a number of comoving observers residing in a neighbourhood of negligible spacetime curvature. The spacetime in between is arbitrary as long as the 1st order geodesic deviation equation is valid. By comparing images of the sky of all the observers, we determine angular diameter distance. Furthermore, we define the parallax distance by noting how position of a source changes if we displace the observation point. The ratio of these distances provide information about an integral of Ricci tensor along the line of sight. Together with Einstein equations, this yields a measure of total amount of matter within an infinitesimal tube connecting both distant regions. The result is independent of 4-velocities of both the observers and the emitter.

### Electromagnetic and gravitational Hopfions

*Tomasz Smołka, KMMF, Uniwersytet Warszawski, Tomasz.Smolka@fuw.edu.pl*

Hopfions are a family of 'solitonary' field solutions which have non-trivial topological structure. I will focus on two physical applications of Hopfions: electromagnetism and linear gravitation. I will show that electromagnetic ( or linearized gravity) field can be quasi-locally described in terms of complex scalar field. New definition of topological charge for linearized gravity will be presented. Using Hopfion solution, I will discuss problem of energy in linearized gravitation. The talk is based on arXiv: 1802.01467

### Physical Relevance of the Lorentz group

*Andrzej Staruszkiewicz, Jagiellonian University, -*

The Author will present arguments that zero frequency part of electromagnetic field is a quantum mechanical rather than classical system, whose symmetry group is the Lorentz group. The "infrared catastrophe" and the "memory effect" will also be discussed.

### The nonlinear stability of the Schwarzschild family of black holes

*Martin Taylor, Princeton University, martint@princeton.edu*

I will present a theorem on the full finite codimension asymptotic stability of the Schwarzschild family of black holes. The proof employs a double null gauge, is expressed entirely in physical space, and makes essential use of the analysis of Dafermos–Holzegel–Rodnianski on the linear stability of the Schwarzschild family. This is joint work with M. Dafermos, G. Holzegel and I. Rodnianski.

### Constructing initial data with partially-prescribed electric and magnetic Weyl curvatures

*Jarrod Williams, Erwin Schrödinger Institute, j.l.williams@qmul.ac.uk*

I will describe how the Gauss–Codazzi–Mainardi equations for an embedded hypersurface can be reduced to a Douglis–Nirenberg elliptic system, given the appropriate choice of determined variables. This opens up the possibility of constructing solutions of the Einstein constraint equations for which certain components of the Weyl tensor (of the resulting spacetime developments) are prescribed as free data, with potential applications to the classical problem of identifying *gravitational degrees of freedom.* In particular, I will describe conditions under which a given time symmetric “background” initial data set admits non-linear perturbative solutions of the Einstein constraint equations of the above-mentioned form, and show that all but one of the conditions are satisfied if the background manifold is sufficiently negatively-pinched.

### Attractors of the Einstein-Klein-Gordon system

*Zoe Wyatt, University of Edinburgh & University of Vienna,*
*zoe.wyatt@ed.ac.uk*

The Milne cosmological model, a specific case of the FLRW family of cosmologies, represents an expanding universe emanating from a big bang singularity with a linear scale factor. With such a slow expansion rate, particularly compared to related isotropically expanding models (such as de Sitter), there are interesting questions one can ask about stability of this spacetime. For example previous results have shown that, when looking at the initial value problem, the Milne model is a stable solution to the vacuum Einstein and Einstein-Vlasov systems. Motivated by the latter, I will present a proof of the stability of the Milne model as a solution of the Einstein-Klein-Gordon system. This result was also recently by J. Wang, but using an alternative gauge and method. Thus I will also compare our method and results. This is based on joint work with D. Fajman.

**Echoes of compact objects: new physics near the surface and matter at a distance**

*Alexander Zhidenko, Universidade Federal do ABC (UFABC), alexander.zhidenko@gmail.com*

It is well known that a hypothetical compact object that looks like an Einsteinian (Schwarzschild or Kerr) black hole everywhere except a small region near its surface should have the ringdown profile predicted by the Einstein theory at early and intermediate times, but modified by the so-called echoes at late times. A similar phenomenon appears when one considers the Einsteinian black hole and a shell of matter placed at some distance from it, so that astrophysical estimates could be made for the allowed mass of the black hole environment. We consider a traversable wormhole and a nonthin shell of matter at a distance. This allows us to understand how the echoes of the surface of the compact object are affected by the astrophysical environment at a distance. The straightforward calculations for the time-domain profiles of such a system support the expectations that if the echoes are observed, they should most probably be ascribed to some new physics near the event horizon rather than some "environmental" effect.