10th Central European Relativity Seminar

February 20-22, 2020, Potsdam-Golm

Schedule

Thursday, 20 February

Chair: Helmut Friedrich

9:30-10:00 Registration

10:00-11:00 **Tom Dutilleul** (Paris XIII) – *Chaotic dynamics of spatially homogeneous spacetimes*

11:00-11:20 **Zoe Wyatt** (University of Edinburgh) – *On the stability of high-dimensional Kaluza-Klein spaces*

11:20-11:40 **Léo Bigorgne** (University of Cambridge) – *Stability of Minkowski spacetime for the massless Einstein-Vlasov system*

11:40-12:00 **Olivier Graf** (Laboratoire Jacques-Louis Lions) – *The spacelike-characteristic bounded L^2 curvature theorem*

12:00-14:00 Lunch break

Chair: Jérémie Joudioux

14:00-14:20 **Caterina Vâlcu** (Ecole Polytechnique) – *Mapping Solutions to the Constraint Equations*

14:20-14:40 **Penelope Gehring** (University Potsdam /AEI) – *Construction of higher dimensional asymptotically hyperbolic initial data sets*

14:40-15:00 **Nicolas Besset** (Grenoble Alpes University) – *The charged Klein-Gordon equation in the exterior De Sitter-Reissner-Nordström spacetime.*

15:00-15:30 Coffee break

Chair: Oliver Rinne

15:30-15:50 **Anxo Biasi** (Jagiellonian University) – *Solvable Resonant Approximations of anti-de Sitter Spacetime*

15:50-16:10 **Hannes Rüter** (Albert Einstein Institute) – *Hyperbolic-like Encounters of Binary Black Holes*

16:10-16:30 **Pedro Cunha** (AEI) – *100 years of light deflection, where we are now: EHT, scalar hair and the M87 supermassive black hole*

16:30-16:50 **Edgar Gasperin** (Instituto Superior Tecnico U Lisbon) – *The Weak Null Condition in Free-evolution Schemes for Numerical Relativity*

Friday, 21 February

Chair: Piotr Bizoń

9:15-10:15 **Dennis Rätzel** (Humboldt Universität zu Berlin) – *Gravitational properties of light*

10:15-10:45 Coffee break

Chair: Peter C. Aichelburg

10:45-11:05 **Thomas Mieling** (University of Vienna) – *The Influence of Earth's Rotation on Electromagnetic Waves*

11:05-11:25 **Marius Oancea** (AEI Potsdam) – *The gravitational spin Hall effect*

11:25-11:45 **Peng Zhao** (Queen Mary University of London) – *Revisiting the characteristic initial value problem: The conformal vacuum Einstein field equations*

11:45-12:05 **Francisco Fernández-Álvarez** (University of the Basque Country) – *A novel characterisation of gravitational radiation in asymptotically flat space-times*

12:05-12:25 **Ivan Booth** (Memorial University of Newfoundland) – *Multiple self-intersections of MOTS during extreme mass ratio mergers*

12:25-14:15 Lunch break

Chair: Herbert Balasin

14:15-14:35 **Maciej Kolanowski** (University of Warsaw) – *Extremal horizons stationary to the second order: New constraints*

14:35-14:55 **Eric Ling** (KTH) – *Spacetime Extensions of the Big Bang*

14:55-15:15 **Maciej Ossowski** (University of Warsaw) – *Non-singular Kerr-NUT-de Sitter spacetimes*

15:15-15:45 Poster session/Coffee break

Chair: Jacek Jezierski

15:45-16:05 **Tomasz Smołka** (University of Warsaw) – *Energy of weak gravitational waves in spacetimes with a positive cosmological constant*

16:05-16:25 **Jinzhao Wang** (ETH Zuerich) – *The small sphere limits of quasilocal masses in higher dimensions*

16:25-16:45 **Boris Daszuta** (Friedrich-Schiller-Universität Jena) – *Numerical scalar curvature deformation and gluing initial data sets*

Saturday, 22 February

Chair: Piotr T. Chruściel

9:15-10:15 **Stefan Hollands** (University of Leipzig) – *Determinism and Quantum Theory inside Black Holes*

10:15-10:45 Coffee break

Chair: Maciej Maliborski

10:45-11:05 **Jose Luis Jaramillo** (Institut de Mathématiques Bourgogne) – *On the stability of black hole quasi-normal modes*

11:05-11:25 **Hans Oude Groeniger** (Kungliga Tekniska Högskolan) – *The initial singularity of Bianchi VI_0 spacetimes with fluid matter*

11:25-11:45 **Filip Ficek** (Jagiellonian University) – *Ground states of spatially confined nonlinear Schrödinger equations in supercritical dimensions*

11:45-12:05 **Claudio Paganini** (University Regensburg/AEI) – *Incompatibility of frequency splitting and spatial localization: A quantitative analysis of Hegerfeldt's theorem*

12:05-12:25 **Piotr Waluk** (Center for Theoretical Physics, PAS) – *Quasi-local mass of weak gravitational field*

Abstracts

Posters

Lie point symmetries of near-horizon geometry equation

Eryk Buk, University of Warsaw, eryk.gabriel.buk@gmail.com

The Lie point symmetries of the near horizon geometry equation were studied. The results will be presented and discussed.

The solution to the Petrov type D equation on the non-trivial bundle topology and its embeddability

Denis Dobkowski-Ryłko, University of Warsaw,
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We consider 3-dimensional isolated horizons (IHs) generated by null curves that form non-trivial $U(1)$ bundles and the Petrov type D equation. From the 4-dimensional spacetime point of view, solutions to that equation define isolated horizons embeddable in vacuum spacetimes (with cosmological constant) as Killing horizons to the second order such that the spacetime Weyl tensor at the horizon is of the Petrov type D. From the point of view of the $U(1)$-bundle structure, the equation couples a $U(1)$-connection, a metric tensor defined on the base manifold and the surface gravity in a very non-trivial way. We focus on the $U(1)$-bundles over 2-dimensional manifolds diffeomorphic to 2-sphere. We have derived all the axisymmetric solutions to the Petrov type D equation. They set 4-dimensional family of horizons and there is a 4-dimensional family of the Kerr-NUT-dS (AdS) spacetimes in the literature. A surprising result is, that generically, our horizons do not correspond to those spacetimes. It means that among the exact type D spacetimes there exists a new 4-dimensional family of spacetimes that generalizes the properties of the Kerr- (anti) de Sitter black holes on one hand and the Taub-NUT spacetimes on the other hand.

BiGONLight: Light propagation in the bi-local geodesic operator framework

Michele Grasso, Center for Theoretical Physics, PAN, grasso@cft.edu.pl

In our recent work [*PRD* 99(6) 064038] we have proposed a new approach to geometric optics in general relativity based on the bilocal geodesic operators (BGO), which extend the previous results in geometric optics and express all optical phenomena in a unified framework. After a brief introduction to the BGO formalism, I will show how the BGO are encoded in the `Mathematica` package *BiGONLight.m* (**Bi**-local **G**eodesic **O**perators framework for **N**umerical

Light propagation) and how it can be used in numerical relativity to compute observables in different spacetimes. As my principal application, I will present how the BGO formalism can be used to isolate the non-linearities in light propagation. The analysis is performed studying the optical properties of the plane-parallel spacetime [*JCAP* 1108 (2011) 024] in three different approximations (linear, Newtonian and Post-Newtonian).

Gowdy spacetimes with a positive cosmological constant

Jerzy Knopik, Vienna University, jerzy.knopik@univie.ac.at

Assuming $U(1)$ symmetry of solutions we construct a fully constrained scheme for Einstein equations on compact spatial domains with $S_2 \times S_1$ and S_3 topology. Performing Geroch reduction and choosing appropriate gauge we rewrite Einstein equations into a system of elliptic and hyperbolic equations which are suitable for numerical computations. Following the approach of Beyer, Escobar and Frauendiener we use spin-weighted spherical harmonics to deal with the singularities of spherical polar coordinates. We apply the scheme to rotating cosmologies initial data with $U(1) \times U(1)$ symmetry found by Bizoń, Simon and Pletka.

A new kind of local symmetry without gauge fields

Andras Laszlo, Wigner Research Centre for Physics,
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In conventional gauge theories, any local gauge symmetry generator is accompanied by a corresponding gauge boson field. This is considered to be quite natural: the role of a gauge field is by definition a compensating field in the covariant derivation to the action of the local gauge transformations on the matter fields. In this talk we show a general relativistic gauge theory-like construction, which is a counterexample to this thumb rule. That is: one can construct a general relativistic field theory, in which the internal symmetries act locally and faithfully on the matter field sector, but not all internal symmetry generators are accompanied by corresponding gauge fields, only the compact generators are. In fact, it can be shown that already the general relativistic Dirac equation has an extremely simplified hidden symmetry of such kind, which demonstrates that such a behavior is not unphysical at all. The main point of the talk will be the Lie group theoretical reason behind the pertinent phenomenon, and its possible application in symmetry unification attempts. (Joint work with Lars Andersson and Blazej Ruba, arXiv:1909.02208)

Elements of N-particle causality theory

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

We propose and study an N-particle extension of the standard causality theory, in which the "N-particle configuration space-time" is defined with the help of a chosen Cauchy temporal function and its associated smooth splitting $\mathcal{M} \simeq \mathbb{R} \times \Sigma$ simply as $\mathbb{R} \times \Sigma^N$, endowed with the causal structure pulled back from $\mathcal{M}$. We then show how the apparent lack of general covariance of this approach — after all the definition involves a fixed notion of time! — is recovered on the level of time-evolution, by employing suitably defined N-particle worldlines. What is more, the developed formalism can also model causality for N-particle probability measures, allowing to study the causal evolution of quantum-mechanical correlations. The talk is based on a joint work with M. Eckstein, P. Horodecki and R. Horodecki.

Evolution equations for a gravitating elastic body in General Relativity

Mikael Normann, Queen Mary University of London, m.normann@qmul.ac.uk

We derive first order equations of motion for an relativistic elastic self-gravitating body (the Einstein-elastic matter system) using orthonormal frames. If the frame is Fermi-Walker propagated and coordinates are chosen such as to satisfy the Lagrange condition, it follows then that the resulting evolution equations are symmetric hyperbolic. In addition, we show the propagation of the constraints of the Einstein-elastic matter system.

Hidden Depths in a Black Hole: Surface Area Information Encoded in the (r, t) Sector

Charles Robson, Tampere University, charles.robson@tuni.fi

Based on an investigation into the so-called "(r, t) sector" of black hole spacetimes, we find that the surface area of the horizon of a black hole is mirrored in the area of a newly-defined surface, which emerges naturally from a study of the intrinsic curvature of the sector at the horizon. We define this new surface for a variety of physical black holes and show that, in each case, the surface encodes horizon information, despite all derivations relying purely on the (r, t) sector of the metrical description. This is a very surprising finding and it provides further evidence to support the conjecture that black holes are, in some sense, fundamentally two-dimensional. These results shine new light on the geometry of black holes and may open the door to a novel two-dimensional interpretation of black hole entropy.

Wormholes in exponential $f(R,T)$ gravity

Pradyumn Sahoo, BITS-Pilani, Hyderabad Campus,
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Alternative gravity is nowadays an extremely important tool to address some persistent observational issues, such as the dark sector of the universe. They can also be applied to stellar astrophysics, leading to outcomes one step ahead of those obtained through General Relativity. In the present article we test a novel $f(R,T)$ gravity model within the physics and geometry of wormholes. The $f(R,T)$ gravity is a reputed alternative gravity theory in which the Ricci scalar R in the Einstein-Hilbert gravitational lagrangian is replaced by a general function of R and T, namely $f(R,T)$, with T representing the trace of the energy-momentum tensor. We propose, for the first time in the literature, an exponential form for the dependence of the theory on T. We derive the field equations as well as the non-continuity equation and solve those to wormhole metric and energy-momentum tensor. The importance of applying alternative gravity to wormholes is that through these theories it might be possible to obtain wormhole solutions satisfying the energy conditions, departing from General Relativity well-known outcomes. In this article, we indeed show that it is possible to obtain wormhole solutions satisfying the energy conditions in the exponential $f(R,T)$ gravity. Naturally, there is still a lot to do with this model, as cosmological, galactical and stellar astrophysics applications, and the reader is strongly encouraged to do so, but, anyhow, one can see the present outcomes as a good indicative for the theory.

Geodesic bilocal operators in static spherically symmetric spacetimes

Julius Serbenta, Center for Theoretical Physics, PAN, julius@cft.edu.pl

We introduce a new, unified formulation of geometrical optics in general relativity. Consider two causally connected, locally flat neighborhoods. Suppose that each null geodesic originating in one neighborhood terminates at the other one, and the curvature along the trajectory is small enough, such that the 1st order geodesic deviation equation holds. Furthermore, let the observation be performed by a number of nearby observers. One can show that all the optical observables, for example the parallax and angular diameter distances, are expressible in terms of bilocal geodesic operators (BGO's), which are functionals of the curvature along the line of sight, and the 4-velocities of the emitter and observer. We derive the BGO's for a static spherically symmetric space-time in two different ways: variation of geodesic curves with respect to their initial data, and by solving geodesic deviation equation together with the use of Killing conserved quantities.

Physical components of an algebraically special solution to the Maxwell equations in the Kerr space-time

Yurii Taistra, Pidstryhach IAPMM NAS of Ukraine, ythelloworld@gmail.com

We have considered the Maxwell equations in the Kerr space-time in the spinor approach with the null condition on the Maxwell field. The Maxwell principal spinors are chosen multiple to one of the Weyl repeated principal spinors. A solution of the equation is obtained by using the method of separation variables and describes outgoing right and left circularly polarized waves. To consider physical components of the electromagnetic field, we have applied orthonormal Kinnersley tetrad. Properties of the electromagnetic field in such an approach are discussed.

Fierz theory vs linear gravity

Marian Wiatr, University of Warsaw, mwiatr@fuw.edu.pl

One of the most popular points of view on linearized gravity is massless spin-2 particle theory. This theory is often used as a starting point to formulate a quantum version of gravity theory. The spin-2 field has well defined local density of energy equal to $\frac{1}{2}(E^2 + B^2)$ in analogy to Maxwell electrodynamics. However, energy in linearized gravity is non local.The relations and differences between linearized gravity and the spin-2 field theory will be discussed.

Some new perspectives on the Kruskal-Szekeres extension

Markus Wolff, Tübingen University, markus.wolff@student.uni-tuebingen.de

It is a well-known fact that the Schwarzschild spacetime admits a spacetime extension in null coordinates which extends the exterior Schwarzschild region past the Killing horizon. This extension is called the Kruskal-Szekeres extension. We will generalize this result to a class of static, spherically symmetric black hole spacetimes by reducing the construction of the spacetime extension to an ODE. Furthermore a solution to the ODE exists if and only if the naturally arising Killing horizon has non-vanishing surface gravity. As is the case for the Kruskal-Szekeres extension, the global null coordinates of the suggested extension come with a set of equations that allow to transform back calculations with respect to the original coordinates. This makes the suggested generalized Kruskal-Szekeres extension a favorable choice of coordinates in this class of spacetimes for studying their null geometry. We will briefly mention some applications of the suggested construction. This is joint work with Carla Cederbaum.

Talks

The charged Klein-Gordon equation in the exterior De Sitter-Reissner-Nordström spacetime.

Nicolas Besset, Grenoble Alpes University,
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We consider a charged and massive scalar field outside the De Sitter-Reissner-Nordström black hole whose evolution is described by the superradiant charged Klein-Gordon equation. We show that the local energy decays in time provided that the product of the black hole charge and the scalar field charge is sufficiently small in comparison to the scalar field mass. We then construct a scattering theory for this equation and interpret it as the existence and invertibility between energy spaces of a trace operator.

Solvable Resonant Approximations of anti-de Sitter Spacetime

Anxo Biasi, Jagiellonian University, anxo.biasi@uj.edu.pl

In this talk we will show that several models based on a scalar field in AdS belong to a well-determined family of resonant systems. This fact immediately provides relevant properties as time-periodic solutions, families of stationary solutions and additional conserved quantities. We will also show that even for models outside our special family, we can extract useful information from the resonant approximation.

Stability of Minkowski spacetime for the massless Einstein-Vlasov system

Léo Bigorgne, University of Cambridge, lb847@cam.ac.uk

In this talk I will present the main ideas of our proof of the stability of Minkowski spacetime for the massless Einstein-Vlasov system with non-compactly supported initial data. In particular, we will see how to differentiate the solutions in order to preserve the null structure of the equations and how to take advantage of it. I will also present certain hierarchies in the commuted equations and how to use them in order to deal with the slow decay rate of the metric. A similar result was proved by M. Taylor under a compact support assumption on the Vlasov field. This is joint work with David Fajman, Jérémie Joudioux, Jacques Smulevici and Maximilian Thaller.

Multiple self-intersections of MOTS during extreme mass ratio mergers

Ivan Booth, Memorial University of Newfoundland, ibooth@mun.ca

We demonstrate that significant features from the complex evolution of marginally outer trapped surfaces (MOTS) during extreme mass ratio mergers can be understood through the study of (non-spherical) marginally outer trapped *open* surfaces (MOTOSs) in Schwarzschild. We examine how these MOTOS can appear, evolve and intersect and show that in the course of the merger they develop an arbitrarily large number of self-intersections. We also (numerically) demonstrate the existence of an apparently infinite family of rotationally symmetric, self-intersecting MOTS fully contained within $r = 2m$. These results significantly extend the recent papers on self-intersecting MOTS by Pook-Kolb, Birnholtz, Krishnan and Schnetter.

100 years of light deflection, where we are now: EHT, scalar hair and the M87 supermassive black hole

Pedro Cunha, AEI, pedro.cunha@aei.mpg.de

Hypothetical ultralight bosonic fields will spontaneously form macroscopic bosonic halos around Kerr black holes, via superradiance, transferring part of the mass and angular momentum of the black hole into the halo. Such process, however, is only efficient if resonant: when the Compton wavelength of the field approximately matches the gravitational scale of the black hole. For a complex-valued field, the process can form a stationary, bosonic field-black hole equilibrium state - a black hole with synchronised hair. For sufficiently massive black holes, such as the one at the centre of the M87 supergiant elliptic galaxy, the hairy black hole can be robust against its own superradiant instabilities, within a Hubble time. Studying the shadows of such scalar hairy black holes, we constrain the amount of hair which is compatible with the Event Horizon Telescope (EHT) observations of the M87 supermassive black hole, assuming the hair is a condensate of ultralight scalar particles of mass 1E20 eV, as to be dynamically viable. We show the EHT observations set a weak constraint, in the sense that typical hairy black holes that could develop their hair dynamically, are compatible with the observations, when taking into account the EHT error bars and the black hole mass/distance uncertainty.

Numerical scalar curvature deformation and gluing initial data sets

Boris Daszuta, Friedrich-Schiller-Universität Jena, boris.daszuta@uni-jena.de

The problem of solving the Einstein constraint equations in vacuum at a moment in time symmetry reduces to a restriction of zero scalar curvature associated with an initial data set. A result due to Corvino [1] provides a technique for local control on the aforementioned set and may be used to engineer initial data with well-defined asymptotics. In short, one may glue together distinct, known solutions from differing regions in a controlled manner forming a new composite solution. The aim of this talk is to demonstrate how a numerical scheme may be directly fashioned out of the above and present results pertaining to a gluing construction without making use of the York-Lichnerowicz conformal framework. Ref: [1]: (Corvino, J.) Scalar Curvature Deformation and a Gluing Construction for the Einstein Constraint Equations. Communications in Mathematical Physics 214, 1 (2000), 137-189.

Chaotic dynamics of spatially homogeneous spacetimes

Tom Dutilleul, Paris XIII, dutilleul@math.univ-paris13.fr

In 1963, Belinsky, Khalatnikov and Lifshitz have proposed a conjectural description of the asymptotic geometry of cosmological models in the vicinity of their initial singularity. In particular, it is believed that the asymptotic geometry of generic spatially homogeneous spacetimes should display an oscillatory chaotic behaviour modeled on a discrete map's dynamics (the so-called Kasner map). We prove that this conjecture holds true, if not for generic spacetimes, at least for a positive Lebesgue measure set of spacetimes.

A novel characterisation of gravitational radiation in asymptotically flat space-times

Francisco Fernández-Álvarez, University of the Basque Country, francisco.fernandez@ehu.eus

A novel criterion to determine the presence of gravitational radiation arriving to, or departing from, null infinity of any weakly asymptotically-simple spacetime with vanishing cosmological constant is given. The quantities involved are geometric, of tidal nature, with good gauge behaviour and univocally defined at null infinity. The relationship with the classical characterisation using the News tensor is analysed in detail. A new balance law at infinity is presented, which may be useful to define 'radiation states'. Work in collaboration and under supervision of José M. M. Senovilla.

References

[1] Francisco Francisco Fernández-Álvarez and José M. M. Senovilla. A novel characterisation of gravitational radiation in asymptotically flat spacetimes. 2019. To appear in Phys. Rev. D: `https://arxiv.org/abs/1909.13796`.

Ground states of spatially confined nonlinear Schrödinger equations in supercritical dimensions

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

Nonlinear Schrödinger equations (NLS), such as Gross-Pitaevskii equation, have been vastly investigated in subcritical dimensions. However, once one moves to higher dimensions, the literature becomes much more scarce. It is caused by lack of the physical motivation and mathematical tools to consider such systems. In this talk I will show how one can encounter higher-dimensional NLS (namely Schrödinger-Newton-Hooke equation) when considering perturbations of the AdS spacetime and present some interesting features common for a broad class of such systems, i.e. spatially confined nonlinear Schrödinger equations in supercritical dimensions.

The Weak Null Condition in Free-evolution Schemes for Numerical Relativity

Edgar Gasperin, Instituto Superior Tecnico U Lisbon,
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All strategies for the treatment of future null-infinity in numerical relativity involve some form of regularization of the field equations. In a recent proposal that relies on the dual foliation formalism this is achieved by the use of an asymptotically Minkowskian generalized harmonic tensor basis. For the scheme to work however, derivatives of certain coordinate light-speeds must decay fast enough. Presently, we generalize the method of asymptotic expansions for non-linear wave equations to treat first order symmetric hyperbolic systems. We then use this heuristic tool to extract the expected rates of decay of the metric near null-infinity in a free-evolution setting. We show, within the asymptotic expansion, that by carefully modifying the non-principal part of the field equations by the addition of constraints, we are able to obtain optimal decay rates even when the constraints are violated. The light-speed condition can hence be satisfied, which paves the way for the explicit numerical treatment of future null-infinity. We then study the behavior of the Trautman-Bondi mass under the decay results predicted by the asymptotic expansion. Naively the mass seems to be unbounded, but we see first that the divergent terms can be replaced with a combination of the constraints and the Einstein field equations, and second that the Bondi mass loss formula is recovered within the framework. Both of the latter results hold in the presence of small constraint violations

Construction of higher dimensional asymptotically hyperbolic initial data sets

Penelope Gehring, University Potsdam /AEI, penelope.gehring@aei.mpg.de

Mantoulidis and Schoen constructed smooth asymptotically flat manifolds of dimension 3 with prescribed horizon boundary, whose total mass can be made arbitrarily close to the optimal value in the Riemannian Penrose inequality, while the geometry of a neighborhood of the horizon is far from being rotationally symmetric; Cabrera Pacheco and Miao obtained a higher dimensional analog to this construction.
Recently, this construction was transferred to the 3-dimensional case for asymptotically hyperbolic manifolds by Cabrera Pacheco, Cederbaum and McCormick. In this talk, we will discuss n-dimensional asymptotically hyperbolic initial data sets, the asymptotically hyperbolic Riemannian Penrose Inequality Conjecture and we will describe the Mantoulidis and Schoen construction for asymptotically hyperbolic initial data sets.

The spacelike-characteristic bounded L^2 curvature theorem

Olivier Graf, Laboratoire Jacques-Louis Lions, graf@ljll.math.upmc.fr

The bounded L^2 curvature theorem of Klainerman-Rodnianski-Szeftel states that the time of existence of a solution to the Einstein vacuum equations is controlled by the L^2 norm of its curvature on spacelike Cauchy hypersurfaces. I will present a version of this result where the curvature is bounded in L^2 on an initial spacelike and an initial null hypersurface. This constitutes the first breakdown criterion for a characteristic Cauchy problem at this level of regularity. The proof relies on global estimates for the Einstein equations in maximal gauge with the initial null hypersurface as a finite boundary. One of the main difficulty is to control the boundary terms arising in these estimates at our level of regularity. This is achieved by choosing the sections of the maximal hypersurfaces on the null boundary to coincide with the so-called *canonical foliation* on the null hypersurface. It requires in turn to show that the canonical foliation exists and is controlled with only finite L^2 curvature flux through the initial null hypersurface. This is a joint work with Stefan Czimek (Toronto).

The initial singularity of Bianchi VI_0 spacetimes with fluid matter

Hans Oude Groeniger, Kungliga Tekniska Högskolan, joog@kth.se

Developments of Bianchi class A spacetimes satisfying Einstein's equations, for various matter sources, can be described by ODE's in expansion-normalized variables, as shown by Wainwright and Hsu. Following these methods, we resolve a conjecture due to Wainwright regarding the initial singularity for the case of Bianchi VI_0 spacetimes with orthogonal perfect fluid matter. In particular, we show that generically the nature of the singularity is vacuum-dominated, anisotropic and silent.

Determinism and Quantum Theory inside Black Holes

Stefan Hollands, University of Leipzig, stefan.hollands@itp.uni-leipzig.de

In classical General Relativity, determinism means that the values of fields on spacetime are obtainable uniquely from their values at an initial time. However, it may occur that the spacetime under consideration is part of a larger spacetime where the evolution, therefore, is not entirely determined by the initial data. This occurs, for example, in the well-known (maximally extended) Reissner-Nordström or Reissner-Nordström-deSitter spacetimes. The "edge" of the region determined by the initial data is called the "Cauchy horizon". It is located inside the black hole. In order to address the problem of indeterminacy beyond this horizon, it has been proposed a long time ago that the Cauchy horizon is, in fact, not existent in practice because the slightest perturbation (e.g. of the metric itself or the matter fields) will catastrophically blow up on there, thereby converting it into a singularity. Recently, however, it has been observed that, classically this is not the case provided the mass, charge, and cosmological constant are in a certain regime. In this paper, we provide arguments that, in such a case, quantum theory comes to the rescue of determinism in the sense that the expected quantum stress tensor is generically singular on the Cauchy horizon. Furthermore, the strength of the singularity cannot be weakened by tuning the mass, charge and cosmological constant unlike in the classical theory. Thus, one can say that quantum theory saves determinism in this situation, rather than undermining it, as often proposed.

On the stability of black hole quasi-normal modes

Jose Luis Jaramillo, Institut de Mathématiques Bourgogne,
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In this talk we explore the issue of black hole QNM instability, by means of a numerical methodology based on pseudospectral methods. More specifically, by adopting a hyperboloidal approach to QNMs we cast the QNM problem as an eigenvalue problem for a non-selfadjoint operator. Such operators suffer potentially of instabilities in their spectrum, and this point is addressed by specific tools in non-selfadjoint spectral theory, among them the notion of pseudospectrum. After studying the Pöschl-Teller potential as a toy model already containing the main features of the discussion, we address the black hole Schwarzschild case. As a result of our analysis, we find strong support to claim: i) the stability of the slowest decaying modes, and ii) the instability of highly damped QNMs. We will conclude with a discussion of the potential implications in astrophysics and fundamental physics.

Extremal horizons stationary to the second order: New constraints

Maciej Kolanowski, University of Warsaw, mp.kolanowski@student.uw.edu.pl

We consider non-expanding shear free (NE-SF) null surface geometries embeddable as extremal Killing horizons to the second order in Einstein vacuum spacetimes. A NE-SF null surface geometry consists of a degenerate metric tensor and a consistent torsion free covariant derivative. We derive the constraints implied by the existence of an embedding. The first constraint is well known as the near horizon geometry equation. The second constraint we find is new. The constraints lead to a complete characterization of those NE-SF null geometries that are embeddable in the extremal Kerr spacetime. Our results are also valid for spacetimes with a cosmological constant.

Spacetime Extensions of the Big Bang

Eric Ling, KTH , eling@math.miami.edu

In this talk we show that a large class of $k = -1$ inflationary FLRW spacetimes dubbed 'Milne-like' admit continuous spacetime extensions through the big bang. For these spacetimes the big bang is a coordinate singularity analogous to how the $r = 2m$ event horizon in Schwarzschild is a coordinate singularity. The geometry of the big bang for Milne-like spacetimes is that of a lightcone in a spacetime conformal to Minkowski space where Lorentz invariance holds at the origin. We discuss how the mathematics of these spacetimes may help provide connections to certain problems in cosmology.

The Influence of Earth's Rotation on Electromagnetic Waves

Thomas Mieling, University of Vienna, thomas.mieling@univie.ac.at

I discuss the influence of Earth's rotation on the propagation of light in optical media. (The discussion equally applies to Earth's rotation about its own axis and around the Sun.) To this end, we shall consider Maxwell's equations in slowly rotating systems in suitable coordinates. For simplicity and with regard to planned experiments at the University of Vienna, I will focus on light propagation in cylindrical step-index waveguides, for which I shall discuss the main perturbations, namely the correction to the dispersion relation and a weak coupling of optical modes with different angular frequency. The former allows to compute phase differences in laser interferometers, allowing for comparison with other effects, such as gravitationally induced phase shifts.

The gravitational spin Hall effect

Marius Oancea, AEI Potsdam, marius.oancea@aei.mpg.de

According to the postulates of General Relativity, test particles without internal structure propagate along geodesics. Similarly, according to geometric optics, high frequency wave packets propagate along null geodesics. However, taking internal structure and backreaction into account leads to modified dynamics, often referred to as spin-orbit coupling. An important manifestation of this phenomenon is the Spin Hall Effect, which manifests as a spin-dependent transverse shift in the particle's trajectory. The spin Hall effect has been experimentally observed for electrons in materials with spin-orbit coupling, as well as for light propagating in an inhomogenous medium. Similar effects are expected to occur for light propagating in a curved spacetime, in the vicinity of a compact object. By considering the WKB approximation for Maxwell's equations, I will briefly present the main steps towards a covariant derivation of the gravitational spin Hall effect of light.

Non-singular Kerr-NUT-de Sitter spacetimes

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Spacetimes with NUT parameter are known to posses a string-like conical singularity along the rotational axis. We present an invariant and coordinate independent approach to find non-singular Kerr-NUT-de Sitter spacetimes. This is done by studying the geometry of space of orbits of the Killing vector field developing a Killing horizon. In the case of Kerr-NUT-de Sitter spacetime we can impose on the horizon H the topology of a non-trivial bundle of $U(1)$ over S_2, where $U(1)$ can be seen as a cyclic time coordinate. We present a new constraint on the parameters (m, a, l, Λ) removing the conical singularity of the space of the null generators of the horizon (i.e. S_2). We then extend our investigation to the neighbourhood of the horizon. Surprisingly, it turns out that the same constraint guarantees that also the future/past of the horizon is non-singular and thus the orbit space has the topology of $H \times \mathbb{R}$.

Incompatibility of frequency splitting and spatial localization: A quantitative analysis of Hegerfeldt's theorem

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In 1974 Hegerfeldt showed that a quantum mechanical system can not be localized in a spatially compact region, or if initially localized will spread instantly and thus violate strong Einstein causality. It follows from Hegerfeldt's theorem that solutions of hyperbolic partial differential equations in $d+1$-dimensional Minkowski space which have spatially compact support cannot be composed purely of positive (or similarly negative) frequencies. In our current work we prove a quantitative version of Hegerfeldt's theorem

Gravitational properties of light

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As Einstein's equations tell us that all energy is a source of gravity, light must gravitate. We can expect the gravitational field of light to be extremely weak. However, the properties of light are premises in the foundations of modern physics: they were used to derive special and general relativity and are the basis of the concept of time and causality in many alternative models. Studying the back-action of light on the gravitational field could give new fundamental insight to our understanding of space and time as well as classical and quantum gravity. In this talk, an overview is given of the gravitational properties of light, in particular, of laser pulses and focused laser beams with well-defined angular momentum. The time-dependence in the case of a laser pulse enables the investigation of the formation of the gravitational field of light. The stationary case of the gravitational field of a focused laser beam shows effects of the fundamental wave properties of light. In particular, parallel co-propagating light-rays are found to deflect each other. Furthermore, the angular momentum of light leads to frame dragging and the rotation of the polarization of a test beam of light.

Hyperbolic-like Encounters of Binary Black Holes

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Using fully general-reativistic simulations, we are investigating the en- counter of two black holes that are initially on a hyperbolic-like orbit. Due to emission of gravitational waves the black holes can eventually become bound and merge. We are particularly interested in the physics near the region between this capture and escape to inifinity.

Energy of weak gravitational waves in spacetimes with a positive cosmological constant

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The Hamiltonian energy, and its flux, of weak gravitational waves on a de Sitter background will be discussed. A new renormalized energy will be proposed. Used asymptotic conditions on the linearized metric have been modeled on the asymptotic behavior of the full solutions of the Einstein equations with positive cosmological constant. Considered space of solutions is greater than the solutions which fulfill so called Bondi asymptotic conditions. This is joint work with P. T. Chruściel and J. Hoque.

Mapping Solutions to the Constraint Equations

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We study initial data in General Relativity, which are defined as solutions to the constraint equations. The focus in this talk is a modified version of the conformal method proposed by David Maxwell. While the model seems more strongly justified from a geometrical standpoint, the resulting system becomes significantly more difficult to solve; it presents critical nonlinear terms, including gradient terms. We describe existence and stability while working in dimensions 3,4 and 5, under smallness assumptions and in the presence of a scalar field with positive potential. The tools we use are related to obtaining a priori estimates (compactness results) and a fixed-point theorem.

Quasi-local mass of weak gravitational field

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An appropriate manipulation of the scalar constraint produces a rather well-known integral formula for the Geroch-Hawking mass. This formula can be easily approximated, up to second order, in a perturbed Minkowski or (anti) de Sitter spacetime. The approximation of Geroch-Hawking mass formula turns out to coincide with the Hamiltonian obtained directly from the canonical formulation of linearized gravity. Moreover, this expression can be divided into a gauge invariant volume integral and gauge dependent boundary terms. I will discuss this derivation and its relevance with respect to the problem of quasi-local mass.

The small sphere limits of quasilocal masses in higher dimensions

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The problem of quasilocal mass has been extensively studied mainly in four dimensions. Here we report results regarding the quasilocal mass in spacetime dimension $n \geq 4$. After generalising three distinct quasilocal mass definitions to higher dimensions under appropriate assumptions, we evaluate their small sphere limits along lightcone cuts shrinking towards the lightcone vertex. The results in vacuum are conveniently represented in terms of the electromagnetic decompositions of the Weyl tensor. We find that the limits at presence of matter yield the stress tensor as expected, but the vacuum limits are in general not proportional to the Bel-Robinson superenergy Q in dimensions $n > 4$.

The result defies the role of the Bel-Robinson superenergy as characterising the gravitational energy in higher dimensions, albeit the fact that it uniquely generalises. Surprisingly, the Hawking energy and the Brown-York energy exactly agree upon the small sphere limits across all dimensions. The "new" vacuum limit W, however, cannot be interpreted as a gravitational energy because of its non-positivity. Furthermore, we also give the small sphere limits of the Kijowski-Epp-Liu-Yau type energy in higher dimensions, and again we see W in place of Q.

On the stability of high-dimensional Kaluza-Klein spaces

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There are a large class of Kaluza-Klein type spacetimes given by the Cartesian product of $1+n$ dimensional Minkowski spacetime with a Ricci-flat Riemannian manifold, called the internal space. These are solutions of the vacuum Einstein equations. This talk will show that these spaces are stable as solutions of the Einstein equations when n is sufficiently large and when the internal space has special geometric structure, in particular relating to its holonomy group. The PDE methods required lie at the intersection of methods for quasilinear wave and Klein-Gordon equations. This stability result is related to a conjecture of Penrose concerning the validity of string theory. This talk is based on joint work with Pieter Blue and Lars Andersson.

Revisiting the characteristic initial value problem: The conformal vacuum Einstein field equations

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Using the Newman-Penrose formalism we study the characteristic initial value problem of the conformal vacuum Einstein field equations. We work in a gauge suggested by Stewart, and following the strategy taken in the work of Luk, demonstrate local existence of solutions in a neighborhood of the set on which data are given. These data are given on intersecting null hypersurfaces satisfying the constraint equations. Existence near their intersection is achieved by combining the observation that the field equations are symmetric hyperbolic in this gauge with the results of Rendall. The main differences from vacuum Einstein field equations are the estimates of conformal factor and the Ricci tensor. To obtain existence all the way along the null-hypersurfaces themselves, a bootstrap argument involving the Newman-Penrose variables is performed.