15th Central European Relativity Seminar

January 22-24, 2025, Nijmegen

Wednesday, January 22

9:30 – 9:50 Registration

9:50 – 10:00 Opening

10:00 – 11:00 **Christoph Kehle** (Massachusetts Institute of Technology) – *Gravitational collapse to extremal Reissner-Nordström and the third law of black hole thermodynamics*

11:00 – 11:20 Coffee break

11:20 – 11:40 **Raya Mancheva** (The University of Edinburgh) – *Two spherically symmetric matter models near the weak null singularity in an Einstein-Maxwell-scalar field spacetime*

11:40 – 12:00 **Tomasz Smołka** (University of Warsaw) – *Interacting Kerr-Newman electromagnetic fields*

12:00 – 12:20 **Ariadna León Quirós** (Universität Tübingen) – *How Robinson's method to prove Black Hole uniqueness influences Geometric Analysis*

12:20 – 14:00 Lunch break

14:00 – 14:20 **Eduardo Hafemann** (University of Hamburg) – *A low-regularity Riemannian positive mass theorem for non-spin manifolds with distributional curvature*

14:20 – 14:40 **Sarah Muth** (Memorial University of Newfoundland) – *The Penrose inequality in spherical symmetry for Gauss-Bonnet gravity*

14:40 – 15:00 **Jordan Marajh** (Queen Mary University of London) – *Controlled regularity at future null infinity from past asymptotic initial data: wave equation*

15:00 – 15:20 Coffee break

15:20 – 15:40 **Oskar Schiller** (Universität Hamburg) – *The Initial Value Formulation of the Einstein Equations in Generalized Geometry*

15:40 – 16:00 **Benjamin Meco** (Uppsala University) – *Uniform Temple charts and applications to null distance*

16:00 – 16:20 **Florian Babisch** (University of Tübingen) – *A new proof of the extended Minkowski inequality via a divergence inequality*

Thursday, January 23

10:00 – 11:00 **Heino Falcke** (Radboud University) – *What's in a shadow? Past, Present and Future of Black Hole Imaging*

11:00 – 11:30 Conference photo and coffee break

11:30 – 11:50 **Carl Rossdeutscher** (University of Vienna) – *Topology and singularities in cosmological spacetimes obeying the null energy condition: Rigidity aspects*

11:50 – 12:10 **Leonardo García-Heveling** (University of Hamburg) – *Reconstructing the Past with the Cosmological Time Function*

12:10 – 12:30 **Phillipo Lappicy** (Universidad Complutense de Madrid) – *Oscillatory spacelike singularities: The Bianchi type $VI_{-1/9}$ vacuum models*

12:30 – 14:00 Lunch break

14:00 – 14:20 **Liam Urban** (University of Vienna) – *Quiescent Big Bang formation in polarized $U(1)$-symmetry*

14:20 – 14:40 **Andrés Franco Grisales** (KTH) – *Developments of initial data on big bang singularities for the Einstein-nonlinear scalar field equations*

14:40 – 15:00 **Maximilian Ofner** (University of Vienna) – *Stability and Instability of Relativistic Fluids in Slowly Expanding Spacetimes*

15:00 – 15:40 Coffee break and poster session

15:40 – 16:00 **Károly Csukás** (Wigner RCP) – *Hyperboloidal initial data without logarithmic singularities*

16:00 – 16:20 **Anna Sancassani** (University of Tübingen) – *Insights on Michel charges in the asymptotically hyperboloidal setting and their evolution*

16:20 – 16:40 **Berend Schneider** (University of Guelph) – *Asymptotically Conserved Quantities in GR*

Friday, January 24

10:00 – 11:00 **Béatrice Bonga** (Radboud University) – *Non-linearities after the collision of two black holes*

11:00 – 11:20 Coffee break

11:20 – 11:40 **Ariadna Ribes Metidieri** (Radboud University) – *Black hole tomography: Unveiling the horizon geometry and dynamics by gravitational waves observations*

11:40 – 12:00 **Sjors Heefer** (Eindhoven University of Technology) – *Gravitational Waves in Finsler Gravity*

12:00 - 12:20 **Patrick Bourg** (Radboud University) – *Importance of non-linearities in a black-hole ringdown*

12:20 - 12:30 Closing

Abstracts

Talks

A new proof of the extended Minkowski inequality via a divergence inequality

Florian Babisch, University of Tübingen,
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Hermann Minkowski established two inequalities in 1903 that provide insights into the geometry of convex bodies. These inequalities highlight the optimality of balls maximizing volume-related integrals and minimizing integrals of mean curvature under surface area constraints. Advancements have been made to extend these inequalities beyond convex domains. Notably, Guan–Li demonstrated their validity for star-shaped domains with strictly mean-convex boundaries using smooth Inverse Mean Curvature Flow (IMCF), while Chang–Wang and Qiu further generalized them to bounded open sets with smooth boundaries through Optimal Transport methods. In 2022, Agositiniani, Fogagnolo, and Mazzieri proved an extended version of the Minkowski Inequality, holding for smooth bounded sets in n-dimensional Euclidean space with dimension greater or equal to three. They used a nonlinear potential theory approach using monotonicity formulas. This is less technical than the IMCF approach. In this short talk I am presenting results of my master's thesis, in which I apply a generalized Robinson's approach to give another proof of the extended Minkowski inequality (under a technical assumption). The proof is based on a parametric geometric inequality derived from a geometric differential inequality in divergence form. This approach is also used in General Relativity by Cederbaum, Cogo, Leandro, and Santos to prove the uniqueness of connected $(3+1)$-dimensional static vacuum asymptotically flat black hole spacetimes.

Non-linearities after the collision of two black holes

Béatrice Bonga, Radboud University, bbonga@science.ru.nl

The gravitational waves emitted by a perturbed black hole ringing down are well described by damped sinusoids, whose frequencies are the so-called quasinormal modes. Typically, first-order black hole perturbation theory is used to calculate these frequencies. Recently, it was shown that second-order frequencies are necessary to model the gravitational-wave signal observed by a distant observer in binary black hole merger simulations. In this talk, I will show that: (1) the horizon of a newly formed black hole after the head-on collision of two black holes also shows evidence of non-linear modes, and (2) discuss some recent progress in second-order black hole perturbation theory.

Importance of non-linearities in a black-hole ringdown

Patrick Bourg, Radboud University, patrick.bourg@ru.nl

After the merger of two black holes (BHs), the distorted remnant BH rings down towards a stationary state through its emission of gravitational waves (GWs). The signal associated with this process is well modelled by a superposition of exponentially damped sinusoids, with complex frequencies given by the so-called quasi-normal modes (QNMs), which are uniquely determined by the mass and spin of the final BH. With a view on future gravitational-wave detectors, the BH spectroscopy program aims at extracting multiple QNMs from ringdown signals in order to perform stringent tests of General Relativity, probe the BH geometry, and constrain features of the surrounding environment. While the linear QNM regime has been extensively studied, recent work has highlighted the importance of second-perturbative-order. In this talk, I will give an introduction to the BH spectroscopy program, a summary of the current status and explain the importance of second-order effects to the QNM ringdown through recent results.

Hyperboloidal initial data without logarithmic singularities

Károly Csukás, Wigner RCP, csukas.karoly@wigner.hu

Merely specifying the free data as asymptotically hyperboloidal, solutions of the vacuum Einstein constraints in general still contain logarithmic singularities at null infinity. In the conformal setup Andersson and Chruściel showed the additional constraints the free data has to satisfy so solutions are free of singularities. Extending the work of Beyer and Ritchie we present the analogous conditions in the evolutionary framework and discuss their relation to the existence of a well defined Bondi mass. We support our claims by numerically constructing asymptotically hyperboloidal perturbed Kerr initial data. Joint work with István Rácz. Part of this work was supported by NSF CAREER Award PHY-2047382 and the Hungarian Scientific Research fund NKFIH Grant No. K-142423.

What's in a shadow? Past, Present and Future of Black Hole Imaging

Heino Falcke, Radboud University, H.Falcke@astro.ru.nl

The interior of black holes is shielded from observation by an event horizon, a virtual one-way membrane through which matter, light, and information can enter but never leave. This loss of information, however, contradicts some basic tenets of quantum physics. Does an event horizon really exist? What are its effects on the surrounding light and matter? What does a black hole really look like? In 2019, the Event Horizon Telescope (EHT) captured the first-ever image of a black hole, observing its dark shadow in the radio galaxy M87. In 2022, the black hole at the center of our Milky Way was imaged. This confirmed the presence of supermassive black holes at the centers of galaxies and provided strong evidence for the presence of an event horizon.

The EHT will continue to grow as new telescopes join the array. For example, the new Africa Millimeter Wave Telescope (AMT), a 15-meter mm-wave radio dish for VLBI and transient science in Namibia, will pioneer the extension of the EHT to the African continent and greatly improve our ability to make movies of the plasma dynamics around black holes. In the future, space-based interferometers will provide even sharper views by orders of magnitude. The combination of black hole movies, multi-wavelength time domain observations, and a new generation of supercomputer simulations will lead us into a new era of black hole astrophysics. This will allow us to understand the energy generation near the event horizon, the formation of powerful jets, probe the extraction of black hole spin energy, and test fundamental predictions of Einstein's theory of general relativity and its alternatives in the most extreme limit.

Developments of initial data on big bang singularities for the Einstein-nonlinear scalar field equations

Andrés Franco Grisales, KTH, anfg@kth.se

In a recent work, Ringström proposed a geometric notion of initial data on big bang singularities. Moreover, he conjectured that initial data on the singularity could be used to parameterize quiescent solutions to Einstein's equations; that is, roughly speaking, solutions whose leading order asymptotics are convergent. We prove that given initial data on the singularity for the Einstein-nonlinear scalar field equations in 4 spacetime dimensions, as defined by Ringström, there is a corresponding unique development of the data. We do not assume any symmetry or analyticity, and we allow for arbitrary closed spatial topology. Our results thus present an important step towards resolving Ringström's conjecture. Furthermore, our results show that the Einstein-nonlinear scalar field equations have a geometric singular initial value problem formulation, which is analogous to the classical result by Choquet-Bruhat and Geroch for initial data on a Cauchy hypersurface. In the literature, there are two conditions which are expected to ensure that quiescent behavior occurs. The first one is an integrability condition on a special spatial frame. The second one is an algebraic condition on the eigenvalues of the expansion normalized Weingarten map associated with a foliation of the spacetime near the singularity. Our result is the first such result where both possibilities are allowed. That is, we allow for the first condition to ensure quiescence in one region of space and for the second condition to take over in the region where the first one is violated. This fact allows for our results to include the vacuum setting.

Reconstructing the Past with the Cosmological Time Function

Leonardo García-Heveling, University of Hamburg,
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In 1998, Andersson, Galloway, and Howard introduced the regular cosmological time function as a way to define the proper time elapsed from the big bang. This time function has good properties on a large family of cosmological spacetimes. For instance, the hypersurfaces of constant time are future-Cauchy, meaning that one can predict the future from knowledge of the present. In this talk, we will discuss if the constant time hypersurfaces are past-Cauchy, i.e., if we can also recostruct the past. The answer is positive, negative, or unknown, depending on the properties of the spacetime considered. This is part of a joint work with Greg Galloway.

A low-regularity Riemannian positive mass theorem for non-spin manifolds with distributional curvature

Eduardo Hafemann, University of Hamburg,
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In this talk, we investigate whether metrics with nonnegative scalar curvature in the distributional sense share any good properties with smooth metrics that have nonnegative scalar curvature in the classical sense. The classical Riemannian positive mass theorem asserts that asymptotically flat manifolds with nonnegative scalar curvature have nonnegative ADM mass. I will show that this statement holds for manifolds whose metrics are only $C^0 \cap W^{1,n}_{loc}$ and smooth outside a compact set. This result essentially removes the spin condition from the main theorem of Lee and LeFloch (2015) when the metric is smooth outside a compact set. The strategy to establish the nonnegativity of the mass relies on smooth approximations of the metric and a Sobolev version of Friedrichs' Lemma, which provides improved convergence for the negative part of the scalar curvature of the smooth metrics, allowing the application of the usual conformal method in lower regularity.

Gravitational Waves in Finsler Gravity

Sjors Heefer, Eindhoven University of Technology, s.j.heefer@tue.nl

We start by outlining the main ideas underlying Finsler gravity, an extension of general relativity based on Finsler geometry, which generalizes pseudo-Riemannian geometry. Then we introduce a class of exact solutions to the Finslerian field equations closely related to the well-known pp-waves in general relativity. The linearized versions of these solutions may be interpretted as Finslerian gravitational waves. We discuss the physical effect of such waves. In particular, we come to the remarkable conclusion that the effect of such a

Finslerian gravitational wave on an interferometer is indistinguishable (at least to first order in the Finslerian perturbation) from that of standard gravitational wave in general relativity.

Gravitational collapse to extremal Reissner-Nordström and the third law of black hole thermodynamics

Christoph Kehle, Massachusetts Institute of Technology, kehle@mit.edu

In this talk, I will present a proof that extremal Reissner-Nordström black holes can form in finite time in gravitational collapse of charged matter. In particular, this construction provides a definitive disproof of the "third law" of black hole thermodynamics. I will also discuss a result showing that extremal black holes take on a central role in gravitational collapse, giving rise to a new conjectural picture of "extremal critical collapse." This is joint work with Ryan Unger (Stanford).

Oscillatory spacelike singularities: The Bianchi type $VI_{-1/9}$ vacuum models

Phillipo Lappicy, Universidad Complutense de Madrid, philemos@ucm.es

The Bianchi type $\mathrm{VI}_{-1/9}$, VIII and IX vacuum models all have 4-dimensional Hubble-normalized state spaces and are expected to have a generic initial oscillatory singularity, but the invariant boundary sets responsible for the oscillations are much more complicated for type $\mathrm{VI}_{-1/9}$ than those of type VIII and IX. For the first time, we explicitly solve the equations on these type $\mathrm{VI}_{-1/9}$ boundary sets and also introduce a new graphic representation of the associated network of heteroclinic chains (i.e. sequences of solutions describing the oscillations). In particular, we give examples of networks of entangled cyclic heteroclinic chains and show that only some of these cyclic heteroclinic chains are asymptotically relevant.

How Robinson's method to prove Black Hole uniqueness influences Geometric Analysis

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In 1977, D. C. Robinson developed a method for proving static vacuum Black Hole uniqueness (DOI: 10.1007/BF00756322). This method has recently been generalized to higher dimensions by C. Cederbaum, A. Cogo, B. Leandro and J. Paolo dos Santos (arXiv:2403.14422). It turns out that the same method can also be used to prove geometric inequalities, such as the Willmore Inequality in Eucledian space by C. Cederbaum and A. Miehe (arXiv:2401.11939). In my talk, I will start by explaining the Robinson style method, and then show how to apply a generalization of it to prove Willmore inequality in manifolds with non-negative Ricci curvature and applications to the proof of Hamilton's pinching condition (joint work with C. Cederbaum).

Two spherically symmetric matter models near the weak null singularity in an Einstein-Maxwell-scalar field spacetime

Raya Mancheva, The University of Edinburgh, s1807954@ed.ac.uk

In this work we investigate two spherically symmetric matter models in the black hole interior of the Einstein-Maxwell-scalar field class of spacetimes. This black hole interior is bounded to the future by a Cauchy horizon $\mathcal{CH}^+$ which is a weak null singularity. Firstly, we consider the Cauchy problem of spherically symmetric dust falling into $\mathcal{CH}^+$ with initial data supplied on a smooth spacelike curve with bounded second curvature tensor. We prove that, under some physically reasonable assumptions, the flow of the dust velocity does not experience any shell-crossing before or at the singularity, and that the dust energy density remains bounded as matter approaches the singularity. Secondly, we consider the characteristic initial value problem for the wave equation with initial data supplied on a bifurcate null hypersurface $\overline{\mathcal{C}_-} \cup \mathcal{C}_+$ such that the closure $\overline{\mathcal{C}}_+$ of the outgoing null hypersurface intersects the Cauchy horizon. Using a bootstrap argument we prove that, under monotonicity assumptions on the double null derivatives of the initial data, the outgoing derivative of the wave function blows up at the singularity.

Controlled regularity at future null infinity from past asymptotic initial data: wave equation

Jordan Marajh, Queen Mary University of London, j.marajh@qmul.ac.uk

We study the relationship between asymptotic characteristic initial data for the wave equation at past null infinity and the regularity of the solution at future null infinity on the Minkowski spacetime. By constructing estimates on a causal rectangle which contains the conformal boundary, we prove that the solution admits an asymptotic expansion near null and spatial infinity whose regularity is controlled quantitatively in terms of the regularity of the data at past null infinity. Our approach makes use of Friedrich's conformal representation of spatial infinity in which we prove delicate non-degenerate Grönwall estimates. We describe the relationship between the solution and the data both in terms of Friedrich's conformal coordinates and the usual physical coordinates on Minkowski space. This is work in collaboration with Juan Valiente Kroon and Grigalius Taujanskas.

Uniform Temple charts and applications to null distance

Benjamin Meco, Uppsala University, benjamin.meco@math.uu.se

Given a point p in a spacetime and a timelike curve C such that $C(0) = p$, a Temple chart centered at p is a variant of a tubular neighborhood of C where one uses the exponential map from C in the null directions to define the coordinates. Notably, one of the coordinates is given by the so called optical function, which can be seen as an indicator function of the causal future of p. Given a spacetime, we show that every point p has a uniform Temple chart, that is, a neighborhood U such that for every q in U there is a Temple chart centered at q that covers U. We then apply these charts to study a spacetime that has been converted into a metric space using the null distance of Sormani-Vega and a time function that is anti-Lipschitz in the sense of Chruściel, Grant, and Minguzzi. Estimating the gradients of the optical functions, we show that the uniform Temple charts are bi-Lipschitz into such a metric space and apply them to recover the local causal structure of the spacetime. Finally, applying a theorem of Hawking we show that a time preserving and null distance preserving bijection between spacetimes must be a Lorentzian isometry provided that some natural assumptions are satisfied. This is joint work with Anna Sakovich and Christina Sormani, and these results will be applied in the upcoming work on Spacetime Intrinsic Flat Convergence.

The Penrose inequality in spherical symmetry for Gauss-Bonnet gravity

Sarah Muth, Memorial University of Newfoundland, smmmuth@mun.ca

The Penrose inequality remains one of the most important unproved conjectures in mathematical general relativity. Its proof would provide evidence for cosmic censorship, and it allows us to answer the question: how much mass is in a given region of spacetime? This talk focuses on my and my colleague's recent work which proves the full spacetime Penrose inequality under the assumption of spherical symmetry, for $n + 1 \geq 3$ dimension in Gauss-Bonnet quadratic curvature gravity. We prove this from the initial data perspective, using a generalized Gauss-Bonnet Hawking mass. Some discussion of future work, including extensions to similar style proofs for Lovelock gravity, will also be included.

Stability and Instability of Relativistic Fluids in Slowly Expanding Spacetimes

Maximilian Ofner, University of Vienna, maximilian.ofner@univie.ac.at

Homogeneous and isotropic solutions to the relativistic Euler equations are known to be unstable on a Minkowski background. However, for FLRW models with a fast expansion rate, relativistic fluids stabilize. This scenario suggests a transition between stable and unstable behavior somewhere along a family of spacetimes parametrized by their expansion rate. In this talk we will explore this phase transition for various equations of state using novel analytical and numerical methods.

Black hole tomography: Unveiling the horizon geometry and dynamics by gravitational waves observations

Ariadna Ribes Metidieri, Radboud University, ariadna.ribesmetidieri@ru.nl

Reconstructing the metric of a perturbed black hole due to the presence of a companion, including both the stationary and radiative contributions, is a highly non-trivial problem. In this talk, we address this to linear order in perturbation theory through the characteristic initial value formulation, prescribing data on two intersecting null hypersurfaces, one of which is a perturbed isolated horizon. By including the possibility of small amounts of infalling radiation at the horizon, we show that the ringdown modes arise naturally in this formalism when there is no incoming radiation from null infinity. This therefore establishes analytically strong correlations between the usual quasi-normal modes observed in the outgoing radiation with the horizon geometry and the infalling radiation at the horizon. This can be viewed as a demonstration of black hole tomography in a perturbative setting, where we are able to determine the detailed dynamics of the horizon geometry based on observations of gravitational waves from the late stage of a binary black hole merger.

Topology and singularities in cosmological spacetimes obeying the null energy condition: Rigidity aspects

Carl Rossdeutscher, University of Vienna, carl.rossdeutscher@univie.ac.at

In the past decades, Hawking's and Penrose's singularity theorems have been substantially modified and strengthened in various directions. In particular, Galloway and Ling have proven a topological singularity theorem using a sign restriction on the second fundamental form K. The restrictive sign condition on K in this Theorem excludes even the interesting time-symmetric case. The purpose of the talk is to relax this expansion condition in several respects. This entails a classification of the abundant non-singular cases which involves subtle topological issues. We facilitate this task by restricting ourselves to prime Cauchy surfaces, as every orientable manifold can be decomposed into a connected sum of primes. We will subsequently show that non-spherical Cauchy surfaces in complete spacetimes are finitely covered by surface bundles over S^1 with fiber totally geodesic MOTS. This is a joint work with Eric Ling, Walter Simon and Roland Steinbauer.

Insights on Michel charges in the asymptotically hyperboloidal setting and their evolution

Anna Sancassani, University of Tübingen, sancassani@math.uni-tuebingen.de

We consider asymptotically hyperboloidal initial data sets (M, g, K), with background data $(\mathbb{H}^3, b, b)$, where $(\mathbb{H}^3, b, b)$ is the standard hyperboloid embedded in Minkowski. We compute charges with respect to the KIDs of this background as done in Michel (B. Michel, Geometric invariance of mass-like asymptotic invariants, arxiv.org/abs/1012.3775). With appropriately chosen asymptotics and direction of evolution, we find that the behavior of these charges is very similar to that in the null setting. This could shed some light on the physical interpretation of these charges on asymptotically hyperboloidal initial data.

The Initial Value Formulation of the Einstein Equations in Generalized Geometry

Oskar Schiller, Universität Hamburg, oskar.schiller@uni-hamburg.de

Generalized geometry is the study of geometrical objects on the generalized tangent space $TM \oplus T^*M$. Fundamental geometrical objects such as the metric, Ricci curvature, and scalar curvature have an analogue in this formalism, hence also the Einstein equations. Imposing these "generalized Einstein equations" is equivalent to the equations of GR coupled to the so-called dilaton and B-Field, quantities that appear in the theory of supergravity. In this talk, we discuss the initial value formulation of the generalized Einstein equations, and provide an elegant formalism to describe the constraint equations for the system. The eventual goal is to establish the existence of an MGHD in this context.

Asymptotically Conserved Quantities in GR

Berend Schneider, University of Guelph, berend@uoguelph.ca

In flat space-times there exist conservation laws associated with solutions to the wave equation on each light cone. Physically, these conservation laws are a consequence of *the strong Huygens principle*; the fact that solutions to the wave equation propagate along light cones. Indeed, the conserved quantities simply represent the value of the field at the vertices of the light cones. Inspired by these conservation laws, I derive analogous 'asymptotically conserved' quantities in asymptotically flat space-times (generalizing the so-called *Newman-Penrose constants*), which become exactly conserved at infinity.

Interacting Kerr-Newman electromagnetic fields

Tomasz Smołka, University of Warsaw, t.smolka@uw.edu.pl

We discuss some properties of the $G \to 0$ limit of the Kerr-Newman solution of Einstein-Maxwell equations. Carter noted the near equality between the gyromagnetic ratio, or g-factor, of the Kerr-Newman solution and of the electron. This observation is a consequence of the multipole structure of the Kerr-Newman field. In contrast to the Coulomb field, this spinning Maxwell field has a finite Lagrangian. Moreover, by evaluating the Lagrangian for the superposition of two such Kerr Newman electromagnetic fields on a flat background, we are able to find their interaction potential. This yields a correction to the Coulomb interaction due to the spin of the field. Joint work with S. Aghapour, L. Andersson, and K. Rosquist. The talk is based on PRD 110, 104053 (2024).

Quiescent Big Bang formation in polarized $U(1)$-symmetry

Liam Urban, University of Vienna, liam.urban@univie.ac.at

The BKL conjecture predicts that the past asymptotic behaviour of generic cosmological spacetimes is dominated by oscillations arising from the geometric evolution. Exceptions to this occur in certain symmetry classes or in presence of exceptional matter types, including scalar field matter. These solutions exhibit a stable or "quiescent" Big Bang toward the past. In this talk, I will present a recent result on quiescent Big Bang formation for Einstein vacuum spacetimes in polarized $U(1)$-symmetry. These solutions are perturbations of spatially homogeneous Kasner-like spacetimes with spatial geometry $M \times \mathbb{S}^1$, where M is a closed surface of arbitrary genus. This result arises as a corollary of stable Big Bang formation for the Einstein scalar-field Vlasov system in $2 + 1$ dimensions, and extends a landmark result by Fournodavlos, Rodnianski and Speck from $\mathbb{T}^3$ to general spatial geometries.

Posters

Photon spheres from a perturbative perspective

Simone Coli, Eberhard Karls Universität Tübingen,
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It is widely recognized that many static, spherically symmetric spacetimes, such as the Schwarzschild solution, feature a photon sphere. The uniqueness of static, asymptotically flat, (electro-)vacuum spacetimes featuring a photon sphere has also been rigorously established. In this talk, we will delve into the questions that emerge from the perturbative approach to studying photon spheres in static spacetimes, as treated by Yoshino in Phys. Rev. D95, 044047.

Local Well-posedenss of the Bartnik Static Extension Problem near Schwarzschild spheres

Ahmed Ellithy, Uppsala University, ahmed.ellithy@math.uu.se

We establish the local well-posedness of the Bartnik static metric extension problem for arbitrary Bartnik data that perturb that of any sphere in a Schwarzschild $\{t = 0\}$ slice. Our result in particular includes spheres with arbitrary small mean curvature. We introduce a new framework to this extension problem by formulating the governing equations in a geodesic gauge, which reduce to a coupled system of elliptic and transport equations. Since standard function spaces for elliptic PDEs are unsuitable for transport equations, we use certain spaces of Bochner-measurable functions traditionally used to study evolution equations. In the process, we establish existence and uniqueness results for elliptic boundary value problems in such spaces in which the elliptic equations are treated as evolutionary equations, and solvability is demonstrated using rigorous energy estimates. The precise nature of the expected difficulty of solving the Bartnik extension problem when the mean curvature is very small is identified and suitably treated in our analysis.

Geodesic Motion in General Relativity

Noah Migoski, University of Tübingen, noah.migoski@student.uni-tuebingen.de

In general relativity, the equivalence principle motivates the hypothesis that freely-falling test particles follow geodesics. At first glance, this geodesic hypothesis seems to be independent of the central equation of general relativity, the Einstein field equation. However, since point-like test particles are an idealization used to approximate sufficiently small extended bodies, their motion should correspond to the motion of such bodies, i.e. it should be determined by Einstein's equation coupled to the conservation law it imposes on the corresponding energy-momentum tensor. In this talk we will explore the proof given by Ehlers and Geroch, and expanded upon by Bezares et al., which shows that geodesic motion is indeed a consequence of Einstein's equation that arises when considering the special case of energy-momentum tensors that can be localized to arbitrarily small neighborhoods of a curve in space-time. By considering the subtleties of this proof, we gain insight into the notion of test particles in general relativity, and how the motion of extended physical bodies described by continuous energy-momentum tensors relates to geodesic motion. We will also compare these results with other methods that seem to be better suited to analyzing deviations from geodesic motion, which is important for physical applications.

A new class of non-Einstein pp-wave solutions to quadratic gravity

Lorens Niehof, Eindhoven University of Technology, l.f.niehof@student.tue.nl

We obtain a new family of exact vacuum solutions to quadratic gravity that describe pp-waves with two-dimensional wave surfaces that can have any prescribed constant curvature. When the wave surfaces are flat we recover the Peres waves obtained by Madsen, a subset of which forms precisely the vacuum pp-waves of general relativity. If, on the other hand, the wave surfaces have non-vanishing constant curvature then all our solutions are non-Einstein (i.e. they do not solve Einstein's equations in vacuum, with or without cosmological constant) and we find that the curvature is linearly related to the value of the cosmological constant. We show that the vacuum field equations reduce to a simple linear biharmonic equation on the curved wave surfaces, and as consequence, the general solution can be written down. We also provide some simple explicit examples.

Inhomogeneous initial data on $\mathbb{S}^3$

John Östör, Radboud University, janos.ostor@gmail.com

We construct generic, inhomogeneous cosmological initial data using a powerful evolutionary reformulation of the constraint equations. The angular sector is resolved fully spectrally and the transverse direction is studied with Fuchsian techniques. We also directly control the GW-radiation content of the solution.

Multipole moments in stationary spacetimes

Jorn van Voorthuizen, University of Cologne, jvoorthu@uni-koeln.de

Multipole moments in general relativity serve as a fundamental tool for characterizing the gravitational field of a system. In this talk, we revisit the formulation of the Geroch–Hansen multipole moments for stationary, asymptotically flat vacuum spacetimes. A particular focus is placed on the well-definedness of these moments, which hinges on the uniqueness of the one-point conformal completion in Geroch's asymptotic flatness framework. Based on Geroch's approach, we establish a revised uniqueness result that addresses gaps in the original formulation, demonstrating that uniqueness holds up to specific conformal transformations. Additionally, we show that the multipole moments transform consistently under these conformal changes, as described by Beig's formula, ensuring their status as well-defined and robust descriptors of the gravitational field. This talk is based on my master's thesis under supervision of Dr. Béatrice Bonga and Dr. Annegret Burtscher.