New applications of unparticles: Inflation, dark energy, bouncing cosmologies, and the Hubble tension

Cosmology & astrophysics

Michał Artymowski

Uniwersytet Kardynała Stefana Wyszyńskiego

Unparticles are a hypothetical new form of matter created from fermions in an $SU(N)$ gauge theory. Unparticles provide a wide spectrum of new cosmological applications. In my talk (based on `arXiv:2010.02998` and `arXiv:1912.10532`), I will show that they can display a cosmological-constant-like behavior, and since then they can be used to generate cosmic inflation or dark energy. I will show realistic bouncing and cyclic Universes filled with unparticles and perfect fluid. I will also discuss constraints on unparticles energy density and their possible role in relaxing the Hubble tension.

Non expanding horizons and null infinity

Plenary talk

Abhay Ashtekar

Pennsylvania State University

Variational formulations of General Relativity

Mathematical relativity I

Bartłomiej Bąk

Uniwersytet Warszawski

Here, I present few results from my Master Thesis. I will focus on the equvalence between three variational principles (called "pictures") used in general relativity: the metric picture (the most popular case, where the metric is the fundamental object), the Palatni picture (here we control both the metric tensor and the connection) and the affine picture (the least known, where only the connection is controlled). Such construction shows quite an interesting fact: the matter could affect the character of the connection or, in other words, the non-metricity of the connection could be interpreted as a matter field. As an example of all this deliberations I will present the model of gravity with the cosmological constant and proposition of unification of the gravity and electromagnetism. Such a model embraces a few classical ideas: 1) Einstein's intuition that gravity is described by the symmetric part and electromagnetism by the skew-symmetric part of a certain geometric object (here: the Ricci tensor), 2) Weyl's concept of non-metric connection, where the measure of "non-metricity" is played by the electromagnetic potential, 3) Born–Infeled generalisation of electromagnetism, where the "standard" Maxwellian theory arises as its weak field approximation. At the end of my talk I show how to use the equivalence between the three variational picures to describe some problems of the so called "Weyl conformal gravity theories" and quite interesting perturbation of the Proca theory.

Cosmology & astrophysics

Dirac procedure and the Hamiltonian formalism for cosmological perturbations in a Bianchi I universe

Alice Boldrin

Narodowe Centrum Badań Jądrowych

We apply the Dirac procedure for constrained systems to the Arnowitt–Deser–Misner formalism linearized around the Bianchi I universe. We discuss and employ basic concepts such as Dirac observables, Dirac brackets, gauge-fixing conditions, reduced phase space, physical Hamiltonian, canonical isomorphism between different gauge-fixing surfaces and spacetime reconstruction. We relate this approach to the gauge-fixing procedure for non-perturbative canonical relativity. We discuss the issue of propagating a basis for the scalar-vector-tensor decomposition as, in an anisotropic universe, the wavefronts of plane waves undergo a non-trivial evolution. We show that the definition of a gravitational wave as a traceless-transverse mode of the metric perturbation needs to be revised. Moreover there exist coordinate systems in which a polarization mode of the gravitational wave is given entirely in terms of a scalar metric perturbation. We first develop the formalism for the universe with a single scalar field and then extend it to the multi-field case. The obtained fully canonical formalism will serve as a starting point for a complete quantization of the cosmological perturbations and the cosmological background.

Plenary talk

Non-Local Gravity cosmology

Salvatore Capozziello

Università di Napoli "Federico II"

Recently the so-called Non-Local Gravity acquired a lot of interest as an effective field theory towards the full Quantum Gravity. In this talk, we sketch its main features, discussing, in particular, possible infrared effects at astrophysical and cosmological scales. In particular, we focus on general non-local actions including curvature invariants like the Ricci scalar and the Gauss–Bonnet topological invariant, in metric formalism, or the torsion scalar, in teleparallel formalism. In both cases, characteristic lengths emerge at cosmological and astrophysical scales. Furthermore, it is possible to fix the form of the Lagrangian and to study the cosmological evolution considering the existence of Noether symmetries.

Recent observations of GWs by LIGO and Virgo detectors

Plenary talk

Giancarlo Cella
Istituto Nazionale di Fisica Nucleare, Sezione di Pisa

The LIGO and Virgo gravitational-wave detectors carried out the first half of their third observing run from April through October 2019. Several new signals where detected, including peculiar events not seen before such as coalescences with a large mass or large mass asymmetry, and coalescences of a neutron star-black hole pair. The analysis of these events is providing information about stellar compact object populations, the nature of black holes and the validity of general relativity. Other searches are constraining more and more the emission of isolated sources and the possible background of gravitational waves from unresolved sources of astrophysical or cosmological nature.

In this talk I will give some highlights about these results, their implications and future perspectives.

From hyperheavenly spaces to two-sided Walker and para-Kähler spaces

Mathematical relativity II

Adam Chudecki
Politechnika Łódzka

The talk is devoted to the neutral 4-dimensional spaces. As a basic structure we consider weak (nonexpanding) hyperheavenly space, i.e. a space equipped with (at least one) integrable, totally null and parallely propagated, 2-dimensional distribution. It is assumed that this distribution is self-dual (SD). If a space is additionally equipped with anti-self-dual (ASD) distribution, it becomes sesquiWalker or two-sided Walker space. The metric of such spaces is discussed. Then it is shown how to specialize the results deeper and get a special type of para-Kähler space. The metric of such a space is analyzed, also in Einstein case. Some interesting metrics of SD and SD-Einstein spaces are also presented.

Accretion of the Vlasov gas on Reissner–Nordström black holes

Numerical methods

Adam Cieślik
Uniwersytet Jagielloński

I will present a stationary spherically symmetric accretion model of the relativistic Vlasov gas on Reissner-Nordström black holes. This model is an alternative to the currently dominant magnetohydrodynamic approach, as the gas characterized by the Maxwell-Jüttner distribution at infinity is no longer in thermal equilibrium in the vicinity of the black hole. The results obtained in 2017 by Paola Rioseco and Olivier Sarbach for the Schwarzschild spacetime as well as those obtained by Patryk Mach and me in 2020 for Reissner–Nordström spacetime show that the radial pressure at the black-hole horizon can be even an order of magnitude smaller than the tangential pressure. In this talk, I will discuss how quantitative characteristics of the Reissner–Nordström model depend on the charge parameter.

Models of quantum gravity

Matter-driven phase transition in CDT

Zbigniew Drogosz
Uniwersytet Jagielloński

Causal Dynamical Triangulations (CDT) is an attempt at formulating a non-perturbative lattice theory of quantum gravity. In dimension higher than two, the main tool used are Monte Carlo simulations. In the recent years, much of the research focused on the case of pure gravity in a four-dimensional universe with the spatial topology of a three-torus. My talk with report on the inclusion of a coupling to dynamical quantum matter fields to such a model. For a sufficiently strong coupling, we observe a new kind of phase transition, which effectively changes the spacetime topology to a simply connected one.

Mathematical relativity I

The Kijowski–Liu–Yau quasi-local mass of the Kerr black hole

Maciej Dunajski
University of Cambridge

Numerical methods

Toroidal magnetic fields in self-gravitating disks around black holes

Wojciech Dyba
Uniwersytet Jagielloński

This talk is based on the paper *Toroidal magnetic fields in self-gravitating disks around black holes* by W. Dyba, P. Mach, M. Pietrzyński (Phys. Rev. D (2021)). We investigate stationary, axial-symmetric models of magnetized, self-gravitating disk rotating according to Keplerian rotation law around black holes. Similarly to the purely hydrodynamical case (i.e. with no magnetic field) bifurcation in the parameter space of solution occurs. There can exist two solutions for a given maximal density within disk and fixed inner and outer radii, differing in the mass of disk. The existence of branch with more massive solutions can be explained by geometrical properties of spacetime. We investigate the influence of the toroidal magnetic field in disk on properties of disk and spacetime. In this talk I will briefly introduce our method and discuss our numerical result.

A nonrelativistic limit for Anti-de Sitter spacetime perturbations

Mathematical relativity II

Filip Ficek

Uniwersytet Jagielloński

When considering the weak field dynamics of a scalar field in the presence of a negative cosmological constant one may perform a non-relativistic limit ($c \to \infty$) and arrive at the Schrödinger–Newton–Hooke equation (SNH). It belongs to the wide class of nonlinear Schrödinger equations that are present in many fields of quantum physics and were very thoroughly investigated in the last century, both by physicists and mathematicians. However, in supercritical dimensions (in case of SNH when $d > 6$) the results are very scarce due to the lack of apparent physical motivation and the breakdown of typically used functional analytic methods. Inspired by the connection with such questions as the stability of Anti-de Sitter spacetime and the soliton resolution problem, we investigate behavior of SNH in supercritical dimensions. In this short talk I present the derivation of SNH as a nonrelativistic limit for Anti-de Sitter spacetime perturbations, sketch the proof of existence of the stationary states in higher dimensions, and discuss their stability.

- P. Bizoń, O. Evnin, and F. Ficek, *A nonrelativistic limit for AdS perturbations*, J. High Energy Phys. 12, 113 (2018)

- F. Ficek, *Schrödinger-Newton-Hooke system in higher dimensions: Stationary states*, Phys. Rev. D 103, 104062 (2021)

Energy reflection and transmission at 2D holographic interfaces

Methods of string theory in gravity

Dongsheng Ge

Uniwersytet Warszawski

Scattering from conformal interfaces in two dimensions is universal in that the flux of reflected and transmitted energy does not depend on the details of the initial state. In this letter, we present the first gravitational calculation of energy reflection and transmission coefficients for interfaces with thin-brane holographic duals. Our result for the reflection coefficient depends monotonically on the tension of the dual string anchored at the interface, and obeys the lower bound recently derived from the ANEC in conformal field theory. The B(oundary)CFT limit is recovered for infinite ratio of the central charges. This talk is based on the work published in Phys. Rev. Lett. 125 (2020) 23, 231602.

Mathematical relativity I

Generalised BSW effect and extraction of energy from extremal electrovacuum black holes

Filip Hejda

Institute of Physics of the Czech Academy of Sciences

In order to extract energy from a black hole by means of Penrose process, production of particles with high relative velocity is needed. For massive particles, this can be achieved in high-energy collisions. Thus, it sparked a lot of attention when Banados, Silk and West (BSW) described a scenario, in which arbitrarily high centre-of-mass collision energies can be achieved. This BSW effect involves particles with fine-tuned angular momentum orbiting a maximally rotating black hole, but an analogous phenomenon was found for particles with fine-tuned charge moving in the vicinity of a maximally charged black hole. Despite many similarities, the two variants differ profoundly in terms of energy extraction. Whereas in the original, centrifugal version, strict unconditional upper bounds on the extracted energy were found, such bounds are absent in the electrostatic one. This contrast is all the more striking, since we recently demonstrated that the two variants can be seen as special cases of a more general effect [Phys. Rev. D 95, 084055 (2017)]. In the present work, we discuss extraction of energy through this generalised BSW effect. We first develop our framework assuming a general extremal electrovacuum black hole, and then validate it using Kerr-Newman solution. Our main conclusion is that there is no unconditional upper bound on the extracted energy whenever both the black hole and the escaping particle are charged. Additionally, we show that collisions in the equatorial plane are immune to further caveats that we found in the simpler case of collisions of charged particles moving along the axis of symmetry [Phys. Rev. D 100, 064041 (2019)].

Cosmology & astrophysics

Numerical study of magnetically dominated jets from accreting black hole sources

Bestin James

Centrum Fizyki Teoretycznej Polskiej Akademii Nauk

Variable accretion flows are a common phenomena in astrophysical black hole sources. Such sources are found at different mass scales, from the cores of active galactic nuclei, e.g. in radio loud objects such as blazars, to gamma ray bursts. Both the gamma-ray bursts and blazars often have a relativistic jet pointing towards or at a small angle from our line of sight. In such sources, the variability of the inflow can be transmitted to the properties of outflows. Some observational studies have shown correlations between the observed jet variability time-scales and Lorentz factor of the emitted jet. Motivated by these observational properties, we investigate the relation between the central engine properties and the variability of the jet outflows by means of numerical GRMHD simulations. We perform axisymmetric simulations of the evolution of a central engine composed of a magnetized torus around a Kerr black hole that results in the launching of a non-uniform jet. We probe the jet energetics at some chosen points along the jet direction and we measure the jet time variability at the chosen regions. We also investigate the angular distribution profile of such jets as they have a more complex structure than a simple top hat.

Polarimetric images of magneticallly arrested accretion flows near the black hole horizon

Cosmology & astrophysics

Agnieszka Janiuk

Centrum Fizyki Teoretycznej Polskiej Akademii Nauk

Magnetically arrested accretion flows are thought to fuel some of the supermassive black holes and to power their relativistic jets. We calculate and study the linear and circular polarimetric images of numerical, high resolution and long duration simulations of magnetically dominated flows . We investigate observational signatures of strong magnetic fields near the event horizon of a non-rotating black hole.

The essence of Gravity

Mathematical relativity I

Jerzy Kijowski

Centrum Fizyki Teoretycznej Polskiej Akademii Nauk

Gravity is a local version of the Newton's First Law: at every spacetime point there is a LOCAL inertial frame. From this point of view the present version of General Relativity Theory represents merely a specific sector of a much more uneversal theory. Other sectors cover electromagnetism and (possibly) the dark matter.

Mathematically, such a theory can be viewed as a realisation of few classical ideas: 1) Einstein: gravity-symmetric and electromagnetism-antisymmetric parts of something more general, 2) Weyl: electromagnetic field is a measure of non-metricity of the connection, 3) Born–Infeld: Maxwell Electrodynamics is merely a linear approximetion of a much more fundamental theory.

Charges of gravity

Models of quantum gravity

Jerzy Kowalski-Glikman

Uniwersytet Wrocławski

In my talk I will argue that it is of interest to investigate gravity in bounded regions, stressing the relevance of corner symmetry algebra. Then I will present an alternative formulation of gravity as a constrained BF theory, which makes it possible to construct the corner charges and their algebra keeping the manifest Lorentz symmetry. I will briefly discuss the obtained results, stressing the difference between our approach and the one motivated by Plebański formulation of gravity.

Mathematical relativity II

Variational approach to conformal geodesics

Wojciech Kryński
Instytut Matematyczny Polskiej Akademii Nauk

Conformal geodesics are distinguished curves in the conformal geometry. They are solutions to a system of third order equations, which makes a Lagrangian formulation problematic. I'll show how enlarging the class of allowed variations leads to a variational formulation for this system with a third order conformally invariant Lagrangian.

Methods of string theory in gravity

Gauge invariant target space entanglement in D-brane holography

Sinong Liu
Uniwersytet Warszawski

It has been suggested in `arXiv:2004.00613` that in Dp-brane holography, entanglement in the target space of the D-brane Yang–Mills theory provides a precise notion of bulk entanglement in the gravity dual. We expand on this discussion by providing a gauge invariant characterization of operator sub-algebras corresponding to such entanglement. This is achieved by finding a projection operator which imposes a constraint characterizing the target space region of interest. By considering probe branes in the Coloumb branch we provide motivation for why the operator sub-algebras we consider are appropriate for describing a class of measurements carried out with low-energy probes in the corresponding bulk region of interest. We derive expressions for the corresponding Renyi entropies in terms of path integrals which can be directly used in numerical calculations.

Cosmology & astrophysics

Accretion of the relativistic Vlasov gas onto a moving Schwarzschild black hole

Patryk Mach
Uniwersytet Jagielloński

I will discuss recent analytic results on the stationary accretion of the relativistic collisionless Vlasov gas onto a moving Schwarzschild black hole. The model assumes that the gas obeys the Maxwell–Juttner distribution at infinity. The Vlasov equation is solved formally in terms of suitable action-angle variables in the framework proposed originally by Rioseco and Sarbach. Depending on the asymptotic temperature, the results interpolate between two regimes: In the limit of infinite asymptotic temperature of the gas, we recover the qualitative picture known form the relativistic Bondi–Hoyle–Lyttleton accretion of the perfect gas with the ultra-hard equation of state, in which the mass accretion rate is proportional to the Lorentz factor associated with the black hole velocity. For low asymptotic temperatures, the mass accretion rate is not a monotonic function of the velocity of the black hole. The model can be applied in situations where the gas is not likely to be in thermal equilibrium in the vicinity of the black hole, for instance in the context of dark matter accretion. The talk is based on two papers written jointly with Andrzej Odrzywołek: Phys. Rev. Lett. 126, 101104 (2021) and Phys. Rev. D 103, 024044 (2021).

Uniqueness of extremal isolated horizons and their identification with horizons of all type D black holes

Mathematical relativity I

David Matejov

Charles University, Prague

We systematically investigate axisymmetric extremal isolated horizons (EIHs) defined by vanishing surface gravity. In the first part, using the Newman–Penrose formalism we derive the most general metric function for such EIHs in the Einstein–Maxwell theory, which complements the previous result of Lewandowski and Pawłowski. We prove that it depends on 5 independent parameters, namely deficit angles on the north and south poles of a spherical-like section of the horizon, its radius (area), and total electric and magnetic charges of the black hole. In the second part of our talk, we identify this general axially symmetric solution for EIHs with extremal horizons in exact electrovacuum Plebański–Demiański spacetimes, using the convenient parameterization of this family by Griffiths and Podolský. They represent all (double aligned) black holes of algebraic type D without a cosmological constant. Apart from a conicity, they depend on 6 physical parameters (mass, Kerr-like rotation, NUT parameter, acceleration, electric and magnetic charges) constrained by the extremality condition. We were able to determine their relation to the EIH geometrical parameters. This explicit identification of type D extremal black holes with a unique form of EIH includes several interesting subclasses, such as accelerating extremely charged Reissner–Nordström black hole (C-metric), extremal accelerating Kerr–Newman, accelerating Kerr–NUT, or non-accelerating Kerr–Newman–NUT black holes.

Gravitational field and quantum entanglement

Models of quantum gravity

Jakub Mielczarek

Uniwersytet Jagielloński

The purpose of this talk is to discuss the relation between the gravitational field and quantum entanglement. Our focus is on the case of Ashtekar's formulation of General Relativity, employing $SU(2)$ gauge fields. I will explain how holonomies of the $SU(2)$ gauge fields are related to maximally entangled two-particle states. The result directly applies in constructing a class o maximally-entangled spin network states in Loop Quantum Gravity. Finally, I will present a few outcomes of simulations of the states on available quantum computers.

Models of quantum gravity

Effective quantum black hole collapse via surface matching

Johannes Münch
CPT Marseille

The fate of matter forming a black hole is still an open problem, although models of quantum gravity corrected black holes are available. In loop quantum gravity (LQG) models were presented, which resolve the classical singularity in the centre of the black hole by means of a black-to-white hole transition, but neglect the collapse process. The situation is similar in other quantum gravity approaches, where eternal non-singular models are available. A strategy is presented to generalise eternal models to dynamical collapse models by surface matching. Assuming 1) the validity of a static quantum black hole spacetime outside the collapsing matter, 2) homogeneity of the collapsing matter, and 3) differentiability at the surface of the matter fixes the dynamics of the spacetime uniquely. It is argued that these assumptions resemble a collapse of pressure-less dust and thus generalises the Oppenheimer-Snyder-Datt model. The junction conditions and the spacetime dynamics are discussed generically for bouncing black hole spacetimes, as proposed by LQG, although the scheme is approach independent. A global spacetime picture of the collapse for a specific LQG inspired model is discussed.

Mathematical relativity II

Freely-falling bodies in standing-wave spacetime

Syed Naqvi
Uniwersytet Jagielloński

The phenomena of standing waves are well known in mechanical and electromagnetic settings where the wave has the maximum and minimum amplitude at the antinodes and nodes, respectively. In the context of the exact solution to Einstein Field equations, we analyze a spacetime that represents standing gravitational waves in an expanding Universe. The study of the motion of free masses is subject to the influence of standing gravitational waves in the polarized Gowdy cosmology with a three-torus topology. We show that antinodes attract freely falling particles and we trace the velocity memory effect.

Models of quantum gravity

Cosmic webs from quantum gravity

Dániel Németh
Uniwersytet Jagielloński

CDT is a numerical approach to quantum gravity that attempts to describe our Universe with the help of Regge Calculus and Path Integral formalism. The study of the past years revealed the rich phase diagram of the model, which contains a physical de Sitter phase with higher-order phase transitions on its borders. Recently we added scalar fields to the model. The classical fields were used as coordinates, which revealed the structure of the CDT Universes which resembled the cosmological voids and webs. During my talk, I will show the most recent results related to scalar fields in the model of Causal Dynamical Triangulations.

Hilbert spaces built over metrics of fixed signature

Models of quantum gravity

Andrzej Okołów
Uniwersytet Warszawski

I will present two Hilbert spaces constructed over the set of all metrics of arbitrary but fixed signature, defined on a manifold. Every state in one of the Hilbert spaces is built of an uncountable number of wave functions representing some elementary quantum degrees of freedom, while every state in the other space is built of a countable number of them. Each Hilbert space is unique up to natural isomorphisms and carries a unitary representation of the diffeomorphism group of the underlying manifold.

Robinson-Trautman spacetimes coupled to conformally invariant electrodynamics in higher dimensions

Mathematical relativity II

Marcello Ortaggio
Institute of Mathematics of the Czech Academy of Sciences

We investigate Robinson-Trautman spacetimes sourced by a conformally invariant, power-like, non-linear electrodynamics in $D > 4$ dimensions. The general solution includes static dyonic black holes with Einstein–Kaehler horizon geometries. In contrast to the linear $D > 4$ theory, time-dependent solutions are also possible which describe black holes gaining (losing) mass by receiving (emitting) electromagnetic radiation. Some extensions beyond Einstein's gravity will be mentioned.

Non-singualar spacetimes with the NUT parameter

Mathematical relativity I

Maciej Ossowski
Uniwersytet Warszawski

The spacetimes with the NUT parameter are commonly associated with an unwanted defect in the form of a singular axis of symmetry. In the case of the Taub–NUT spacetime one of the remedies is the Misner's interpretation: by compactifying the orbits of the cyclic time symmetry one discovers that the spacetime has a structure of the Hopf fibration. Then Taub–NUT may be regarded as a smooth "regularizer" of the Schwarzschild solution curing the curvature singularity at r=0. I will discuss how this construction may be generaalized to black hole spacetimes which include more parameters: Kerr rotation, cosmological constant and acceleration. Suprisingly, additional parameters do not necessarily lead to more restrictive conditions for non-singularity. The basic idea of the extension of Misner's interpretation to more general spacetimes is to find Killing vector fields generating the non-singular orbit space and subsequently impose the $U(1)$-principle bundle structure onto the spacetime. This leads to spacetimes without singular axis for all admissible parameters, and even to completely singularity-free spacetime for a subfamily of accelerated Kerr–NUT–(anti-) de Sitter (i.e. general Plebański–Demiański, type D, black hole solution). The application of the non-singular interpretation to Killing horizons and cosmology will be presented.

Methods of string theory in gravity

Deforming spin chain representation for AdS3 string model

Jacek Pawełczyk
Uniwersytet Warszawski

We describe integrable deformations of integrable spin chains describing AdS3 string models. In particular we show how to deal with TBA equation in the mirror kinematics.

Models of quantum gravity

Approximate Killing symmetries in non-perturbative quantum gravity

Marcus Reitz
Uniwersytet Jagielloński

An open question in quantum gravity is if and how small scale fluctuations and inhomogeneities behave in such a way that at some larger scale they can be well approximated by a geometry with some number of exact symmetries. Causal Dynamical Triangulation (CDT) is a non-perturbative approach to quantum gravity, based on a lattice regularisation of space-time, in which these kind of questions can possibly be addressed. After a short introduction of the framework, I will present a specific notion of approximate Killing vectors that can be generalised to simplicial manifolds using the framework of discrete exterior calculus. These discrete approximate Killing vectors show promise as an observable to study effective symmetries in quantum gravity. I will present a comparison between three different two-dimensional toy-models of quantum gravity, CDT, Dynamical Triangulations and small perturbations around flat space.

Plenary talk

Collisionless kinetic gas configurations surrounding black holes

Olivier Sarbach
Universidad Michoacana de San Nicolás de Hidalgo

I will give a summary of recent work regarding the behavior of a collisionless kinetic gas cloud in the exterior of a black hole spacetime. In the first part of the talk, stationary solutions of the Vlasov equation on a Schwarzschild background will be discussed, including solutions representing steady-state accretion flows and other solutions describing static tori. The second part of the talk is devoted to the phase space mixing effect, which provides a mechanism for the approach to equilibrium even though collisions between the gas particles are completely neglected.

Gravitational standing wave in the Halilsoy–Gowdy spacetime

Gravitational waves

Szymon Sikora
Uniwersytet Jagielloński

In 1988 Halilsoy proposed an exact solution to the Einstein equations, which describe cross-polarized Einstein–Rosen waves. By some complex transformations, this solution can be transformed into the form of the Gowdy cosmological model. We use this solution as a toy model, which is useful to study the polarization of the standing gravitational wave.

Hamiltonian charges in spacetimes with a positive cosmological constant

Mathematical relativity I

Tomasz Smołka
Uniwersytet Warszawski

Hamiltonian charges, and their fluxes, of weak gravitational waves on a de Sitter background will be discussed. We compare the results with their counterparts for Maxwell theory and scalar field respectively. 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.

Electromagnetic standing waves coupled to gravity

Mathematical relativity II

Sebastian Szybka
Uniwersytet Jagielloński

We present an example of electromagnetic standing waves coupled to gravity (an exact solution) and investigate the behavior of electrically neutral test particles.

The Bondi-Sachs metrics with smooth scri $\mathscr{I}$

Mathematical relativity I

Jacek Tafel
Uniwersytet Warszawski

We consider the vacuum Bondi–Sachs metrics admitting conformal compactification which is smooth up to the scri $\mathscr{I}^+$. We expand metric and the Einstein equations into inverse powers of the affine distance r. Metric coefficients are defined in a recursive way. In the case of a stationary solution with nonvanishing mass we show that it is approximately the Kerr metric with extra parameters which can appear in higher order terms in $1/r$. For nonvanishing cosmological constant all free data are located on $\mathscr{I}^+$ and there are linear constraints on the Bondi mass and angular momentum aspects.

Mathematical relativity II

Twisting non-shearing congruences of null geodesics, almost CR structures, and Einstein metrics in even dimensions

Arman Taghavi-Chabert

Uniwersytet Warszawski

We investigate the geometry of a twisting non-shearing congruence of null geodesics on a conformal manifold of even dimension greater than four and Lorentzian signature. We give a necessary and sufficient condition on the Weyl tensor for the twist to induce an almost Robinson structure, that is, the screen bundle of the congruence is equipped with a bundle complex structure. In this case, the (local) leaf space of the congruence acquires a partially integrable contact almost CR structure of positive definite signature. We give further curvature conditions for the integrability of the almost Robinson structure and the almost CR structure, and for the flatness of the latter.

We show that under a mild natural assumption on the Weyl tensor, any metric in the conformal class that is a solution to the Einstein field equations determines an almost CR-Einstein structure on the leaf space of the congruence. These metrics depend on three parameters, and include the Fefferman–Einstein metric and Taub–NUT–(A)dS metric in the integrable case. In the non-integrable case, we obtain new solutions to the Einstein field equations, which, we show, can be constructed from strictly almost Kaehler–Einstein manifolds.

Plenary talk

Space-times with all Penrose limits diagonalisable

Paul Tod

Oxford University

We consider the problem of finding all (four-dimensional) space-time metrics for which all plane-wave Penrose limits are diagonalisable plane waves. This requirement leads to a conformally invariant differential condition on the Weyl spinor which we analyse for different algebraic types in the Petrov-Pirani-Penrose classification. The only vacuum examples, apart from actual plane waves which are their own Penrose limit, are some of the nonrotating type D metrics, but some nonvacuum solutions can also be given explicitly. The condition requires the Weyl spinor, whenever it is nonzero, to be proportional to a valence-4 Killing spinor with a real function of proportionality.

Gravitational holonomies and quantum entanglement

Models of quantum gravity

Tomasz Trześniewski
Uniwersytet Jagielloński

A gauge field theory is often characterized by the holonomies i.e. the parallel transport of gauge group elements along paths in space. It turns out that (at least in the case of $SU(2)$) a holonomy can also be treated as an isomorphism between the two projective Hilbert spaces associated with the beginning and ending of the path. A simultaneous change of bases of these vector spaces is equivalent to a gauge transformation. Furthermore, every holonomy naturally determines a maximally entangled state belonging to the tensor product of the above mentioned Hilbert spaces. On the other hand, if we start with any maximally entangled state of a bipartite system, it corresponds to a unitary map between the Hilbert spaces of subsystems. Such a map transforms under a simultaneous change of their bases in the same way as a holonomy of a gauge field, at least in some cases. The discussed relation between gauge fields and entanglement can be applied to construct tensor networks by the parallel transport of initially non-entangled states, as well as to describe the spin network states (basic constituents of loop quantum gravity) in terms of entanglement.

Quantum groups and asymptotic symmetries

Models of quantum gravity

Josua Unger
Uniwersytet Wrocławski

In this talk the basic ideas behind non-commutative geometry implemented by quantum groups are motivated and introduced. Then, as the main new idea, this framework is ported to the description of asymptotic symmetries of spacetime. On these infinite dimensional symmetry algebras the consistent quantum groups are classified and various mathematical and phenomenological consequences are investigated.

Three roads to the Hamiltonian formulation of field theories with boundaries

Models of quantum gravity

Valle Varo
Universidad Carlos III de Madrid

This presentation will explore three different ways to obtain the Hamiltonian formulation of field theories linear in velocities in bounded regions. Two of them rely on the geometric constraint algorithm applied to the cotangent bundle and the tangent bundle. The third one makes direct use of the equations of motion. The goal is to provide efficient and easy-to-use Hamiltonian methods when boundaries are present before proceeding to quantization. As a testbed, we'll use a generalization of the Pontryagin and Husain—Kuchař actions to four-dimensional manifolds with boundaries, relevant to discuss general relativity.

Gravitational waves

Probing gravitational waves from pulsars in Brans–Dicke theory

Paritosh Verma

Narodowe Centrum Badań Jądrowych

I shall discuss the theoretical background for the data analysis of gravitational waves (GWs) from spinning neutron stars in Brans–Dicke (BD) theory. Einstein's general theory of relativity (GR) predicts only two tensor polarization states but a generic metric theory of gravity can also posses scalar and vector polarization states. The BD theory attempts to modify the GR by varying gravitational constant G, and it has three polarization states. The first two states are the same as in GR, and the third one is the scalar polarization. We derive the response of a laser interferometric detector to the GW signal from a spinning neutron star in BD theory. We obtain a statistic based on the maximum likelihood principle to identify the signal in BD theory in the detector's noise. This statistic generalizes the well known F-statistic used in the case of GR. We perform Monte Carlo simulations in Gaussian noise to test the detectability of the signal and the accuracy of estimation of its parameters.

Cosmology & astrophysics

Is backreaction in cosmology a relativistic effect? On the need for a non-Euclidean extension of Newton's theory

Quentin Vigneron

Uniwersytet Mikołaja Kopernika

Cosmological backreaction corresponds to the effect of inhomogeneities of structure on the expansion of the Universe. The main question surrounding this phenomenon is whether or not it could explain the recent acceleration of the scale factor, also known as Dark Energy. One of the most important result on this subject is the Buchert-Ehlers theorem (Buchert & Ehlers, 1997), which states that backreaction is exactly zero when calculated using Newton's theory of gravitation, which is not the case with general relativity. It is generally said that this result implies that backreaction is a purely relativistic effect. I will show that this is not necessarily the case. Especially the result is only valid for a universe with a Euclidean geometry, and must therefore be generalised for non-Euclidean geometries. This requires the construction of a non-Euclidean extension of Newton's theory.

Quasinormal modes of black holes

Plenary talk

Claude Warnick

University of Cambridge

It has been known since numerical studies in the early '70s that a perturbed black hole will typically return to its ground state by emitting radiation at certain characteristic (complex) frequencies. These "quasinormal" frequencies carry information about the geometry of the black hole. The last few years have seen new mathematical approaches to understand the spectral problem underlying the determination of the quasinormal frequencies for a particular spacetime. In this talk I will review these new approaches and their connection to the underlying physical problem.

Linearized gravity in electrodynamical language, and its full deparametrization

Mathematical relativity I

Marian Wiatr

Uniwersytet Warszawski

Evolution of electrodynamic field on a bounded region, can be described by evolution of two independent functions fulfilling wave equations. Using spin-2 field theory (in Fierz-Lanczos formulation), which is very analogous to electrodynamics, we can deparametrize linear gravity into independent degrees of freedom. In this variables I will show reduced symplectic form, and derivation of quasilocal energy. Finally, I will summarize essential difference and relation between linear gravity and spin-2 field theory.

Multi-messenger astronomy in O4

Gravitational waves

Adam Zadrożny

Narodowe Centrum Badań Jądrowych

The first signal from merging binary neutron stars (BNS) was observed in 2017 as an event named GW170817. This was the first truly multimessenger event observed both in optical and gw bands. This signal, unlike previously detected mergers of binary black hole systems, was not short but counted in tens of seconds. This feature of BNS type signals opens a new possibility to detect a signal prior to a coalescence, thus informing the astronomical community tens of seconds before the actual event. A prototype of the system has already been developed and tested by LIGO–Virgo–Kagra and it is planned to be operational for O4. In the talk, I would like to focus on what changes for multi-messenger astronomy and short-GRB observations in O4.

Models of quantum gravity

First-order quantum correction in coherent state expectation value of Loop-Quantum-Gravity Hamiltonian

Cong Zhang
Uniwersytet Warszawski

Given the non-graph-changing Hamiltonian $\widehat{H[N]}$ in Loop Quantum Gravity (LQG), $\langle\widehat{H[N]}\rangle$, the coherent state expectation value of $\widehat{H[N]}$, admits an semiclassical expansion in ℓ_{p}^2. In this paper, we explicitly compute the expansion of $\langle\widehat{H[N]}\rangle$ to the linear order in ℓ_{p}^2 on the cubic graph with respect to the coherent state peaked at the homogeneous and isotropic data of cosmology. In our computation, a powerful algorithm is developed, supported by rigorous proofs and several theorems, to overcome the complexity in the computation of $\langle\widehat{H[N]}\rangle$. Particularly, some key innovations in our algorithm substantially reduce the complexity in computing the Lorentzian part of $\langle\widehat{H[N]}\rangle$. Additionally, some quantum correction effects resulted from $\langle\widehat{H[N]}\rangle$ in cosmology are discussed at the end of this paper.