Virtual Conference of the Polish Society on Relativity 2020

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Book of Abstracts

Contents

Mathematical and Numerical Relativity / 88

On the Einstein flow in 2+1 dimensions

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It is well known that the Einstein equations can be interpreted as a system of PDEs describing a geometric flow - a continuous family of Riemannian metrics on a given topological manifold.
In this perspective the global structure of solutions to the Einstein equations is analysed using this geometric flow to obtain information on the asymptotic behaviour towards future and past. In this talk we consider this problem in the context of 2+1-dimensional solutions of the Einstein equations and present a result on the future dynamics of general initial data on closed hyperbolic surfaces for the vacuum Einstein equations with a cosmological constant.

Mathematical and Numerical Relativity / 89

Quasi-local energy and Oppenheimer-Snyder collapse

Author: Naqing Xie[1]

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In this talk, we investigate the gravitational collapse of the Oppenheimer-Snyder dust cloud with spatially constant matter density from a quasi-local perspective. Given a closed two-surface within the star, three versions of the quasi-local energy are discussed.
This talk is based on a recent paper with Xiaokai He [Class. Quantum Grav. 37(2020)185016, arXiv:2005.04659].

Mathematical and Numerical Relativity / 90

Nonlinear metric perturbations and their applications

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I will show how to generalize classical results on linear metric perturbations to any higher orders of perturbation expansion and discuss some possible applications.

Mathematical and Numerical Relativity / 14

Gravitational dynamics in the Higgs-dark matter sector

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During the talk the course and results of gravitational collapse within the Higgs-dark matter sector using the double null formalism will be presented. The employed model consists of two scalar fields non-minimally coupled to gravity, one of which is charged under a U(1) gauge field and represents a stable dark matter candidate. The uncharged scalar may represent a real part of the Higgs doublet. There is another U(1) gauge field which can be associated with the dark photon. Two coupling channels among the ordinary matter and dark sectors, namely the kinetic mixing among the U(1) gauge fields and the Higgs portal coupling among scalars, were included in the model.
The structures of emerging spacetimes will be analyzed via locations of dynamically formed horizons and singularities. The dependence of the characteristics of forming objects, precisely dynamical black holes, on the parameters of the model of interest, will be presented. Additionally, a set of spacetime quantities as seen by an observer moving with the medium will be proposed to describe the outcomes of the processes.

Mathematical and Numerical Relativity / 25

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 several quasilocal mass proposals in spacetime dimensions $n \geq 4$. 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.

Mathematical and Numerical Relativity / 66

Conformal fields and integrals of motion in pp waves and electromagnetic fields

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The problem of integrals of the motion for the conformal Killing fields in curved space-times equipped with electromagnetic backgrounds will be analysed. In particular, for the pp-wave spacetimes the ex-

plicit form of conserved charges will be presented. Relations between these charges and symmetries will be discussed in various Lagrangian and Hamiltonian approaches.

Mathematical and Numerical Relativity / 56

Non-singular Kerr-NUT-(anti-)de Sitter spacetimes with projectively non-singular horizons

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Spacetimes with NUT parameter are known to posses a string-like conical singularity. We present a method for obtaining non-singular Kerr-NUT spacetimes with an arbitrary cosmological constant, via an analogue of the Misner interpretation of Taub-NUT spacetimes. Among the non-singular solution there is a class for which also one of the horizons is projectively non-singular, i.e. its space of null generators is non-singular. The horizon is found to be always a cosmological one (but possibly with a negative mass) and non-extremal. The topology of such non-singular horizon is of a non-trivial bundle of $U(1)$ over S^2 and can be extended onto the spacetime in such way that the global topology is $S^3 \times \mathbb{R}$. We provide a geometric interpretation of the non-singular structures on the spacetime, our approach relies on the space of orbits of the Killing vector field of a particular Killing vector field.

Mathematical and Numerical Relativity / 38

Quasi-local mass of weak gravitational field

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The widely accepted ADM expression for the energy of an asymptotically flat spacetime satisfies a "natural" consistency test - its second variation is equal to the canonical hamiltonian functional for linearized gravity on a Minkowski background. A viable quasi-local mass candidate should posses a similar property, namely - its second-order approximation should equal the hamiltonian of the well-understood linearized theory.
We show that the Hawking quasi-local mass passes this test, provided that certain gauge conditions are fulfilled. We believe that these gauge conditions may actually carry a physical meaning - they provide a suggestion about the way the problem of quasi-local energy should be posed.

Mathematical and Numerical Relativity / 59

General Relativistic Shock Waves that Induce Cosmic Acceleration

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A family of global shock-wave solutions of the Einstein field equations for a perfect fluid are constructed. These shock-wave solutions consist of an interior self-similar expanding wave and an exterior self-similar static wave, separated by a spherical shock surface. The interior and exterior fluids are assumed to have isothermal equations of state of the form $p = \sigma\rho$ and $\bar{p} = \bar{\sigma}\bar{\rho}$ respectively, with the strictly positive constants σ and $\bar{\sigma}$ representing a single parameter for each wave. The interior wave has an additional parameter, denoted by a, which represents how perturbed this wave is from a Friedmann-Lemaître-Robertson-Walker spacetime with the same equation of state. The joining of the interior and exterior waves forms a shock-wave solution when mass and momentum are conserved across the shock surface, which places a constraint on the three parameters. The resulting shock-wave solution is thus a two-parameter family of solutions. For $\sigma = \bar{\sigma}$, the two-parameter family becomes a one-parameter family and such solutions model the general relativistic version of an explosion within a static, singular, isothermal sphere. Interestingly, the two-parameter family of shock waves solve the Einstein field equations in the absence of a cosmological constant, but despite this, a cosmic acceleration is still present in the interior wave, with the acceleration parameterised by a. This fact follows from the pioneering work of Smoller and Temple. The presence of this acceleration in the absence of a cosmological constant opens up the question of whether a vast primordial shock-wave could give rise to the cosmic acceleration observed today without the need for dark energy.

Mathematical and Numerical Relativity / 55

UNIQUE REGULAR INTERIOR SOLUTION FOR THE SLOWLY ROTATING KERR BLACK HOLE

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I will present the $NoHair$ result for the solution of Einstein equations describing the non-vacuum regular interior and the vacuum exterior of a spinning black hole. There are only two parameters characterizing the vacuum exterior and two parameters for the non-vacuum regular interior of a spinning black hole.
These two sets of two parameters are connected by the matching condition for the interior and the exterior solutions on the apparent horizon. The solution depends on two parameters for which one can choose the mass M and the angular momentum $J = Ma$ characterizing the vacuum exterior Kerr metric. The unique regular source of the Kerr gravitational field rotates rigidly with the angular velocity Ω equal to the angular velocity Ω_H of the Kerr black hole horizon. The exterior vacuum solution is given by the well-known Kerr metric while the interior metric is completely new.

My result settles the problem posed by R. P. Kerr in 1963 in the case of slow rotation. This is the $NoHair$ result for the regular spinning black holes such as those indirectly observed in nature and thus it should have a bearing on the description of the final states of mergers of binary black holes detected by LIGO and Virgo gravitational wave detectors.

Relativistic Astrophysics / 80

Simulations of Supermassive Black Hole Binaries on their way to Merger

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Supermassive black hole mergers are one of the most dramatic phenomena in the Universe. For a few hours, they can emit as much power in gravitational waves as all the stars in the Universe produce in light. Moreover, they are an important element in determining the mass distribution of the entire population of supermassive black holes. However, none has yet been caught in the act, in large part because they are rare, and no one knows what sort of light they should emit along with the gravitational waves. In this talk, I will present new simulations aimed at providing detailed astrophysical knowledge about the environments close to supermassive black hole binaries on their way to merger. I will show how gas flows in the immediate neighborhoods of these binaries, especially when both black holes are spinning, and present calculations of jet launching and light signals that observers should search for in order to find examples.

Relativistic Astrophysics / 81

Hydrodynamics of superfluid neutron stars

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Neutron stars are an extraordinary laboratory in which to study matter in extreme conditions of density, magnetic energy and gravity. Modelling the interior of these objects requires an understanding of high density physics and phenomena such as superfluidity, which are well known in laboratory settings, but must now be understood in a strong gravity, relativistic setting. This issue is particularly crucial now, as the LIGO and VIrgo detectors have made their first detections of gravitational waves, and have opened up an entirely new window to probe the physics of neutron stars.

In this talk I will describe some of the ongoing work at the Nicolaus Copernicus Astronomical Center, and focus on efforts to model superfluidity in neutron stars, also in a relativistic setting. I will also discuss how electromagnetic and gravitational wave observations can be used together to constrain the models and further our understanding of fundamental physics.

Relativistic Astrophysics / 82

GRBs pancromatic events observed even to the GEV ad TeV emission and their implications as cosmological standard candles

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GRBs are panchromatic events, very attractive sources of study from very high energy (GeV and TeV) to very low frequency until radio. This gives the unique opportunity to study their emission mechanism in multiwavelength. Relevant cases are the GRB 190114C observed by the Major Atmospheric Gamma Imaging Cherenkov telescopes detected above 0.2 TeV, recording the most energetic photons ever observed. I will discuss the implications of such discovery. There are many intriguing cases of GRBs observed at high energy by the Fermi satellites. One of the most important issue in

GRB investigation is their wide range of energies and features which make difficult an exact classification.

I will discuss on how GRBs at high energy will obey correlations among prompt and afterglow parameters and what it is the implication for the use of GRBs as cosmological probes.

Relativistic Astrophysics / 24

Mutual interaction of binary black hole and misaligned circumbinary disk

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The talk will cover the recent numerical investigation of a system composed of a Supermassive Black Hole Binary (SMBHB) and a non-self-gravitating, thin, locally isothermal, viscous disk.

The evolution of such a configuration is relevant not only for the expected gravitational-wave signal, but also for electromagnetic searches for SMBHB candidates. In 2-dimensional, Newtonian, numerical simulations, we analyze the influence of the two model parameters: q — the *mass ratio* of the binary and ι — the *inclination angle* between the binary and the disk. We found that configurations with relatively low mass ratio, composed of central mass and satellite mass, always settle down in a *quasi steady state.* On the other hand, configurations characterized by equal or comparable masses may manifest an inability to reach quasi steady state for inclinations $\iota \in (20°, 55°)$. This problem does not exist for moderately inclined or highly inclined configurations, i.e., inclinations $\iota \leq 20°$ or $\iota \geq 55°$. We try to understand the nature of these phenomena by investigating the binary and viscous torque densities which determine the disk's final density distribution and, in particular, the size of the *central gap.*

Relativistic Astrophysics / 45

Galactic Center S cluster as a reservoir of strong-gravity probes

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Recently, Peissker, Eckart, Zajacek et al. (2020) have reported the discovery of six faint stars in the innermost cluster of the Galaxy, so-called S cluster. These stars, S4711-S4715 and S62, can be monitored in the near-infrared K-band using both photometry and spectroscopy. Their elliptical orbits around the supermassive black hole (Sgr A*) break several records. S4711 with the orbital period of 7.6 years is the shortest period star around Sgr A.* S4714 has a large orbital eccentricity of 0.985 and can potentially reach about 8% of the light speed at its pericenter, which would make it the fastest star detected so far. We characterize these stars in terms of the general relativistic parameter. For future monitoring, we will show predictions of the Schwarzschild precession as well as the Lense-Thirring precession. S62, S4711, and S4714 have the potential to exhibit the Lense-Thirring precession of their ascending nodes from a fraction of an arcsecond up to a few arcseconds per year, depending on the exact orientation as well as the magnitude of the spin of Sgr A. *These stars are thus unique probes of the space-time around Sgr A* on the scale of a few 100 Schwarzschild radii.

Relativistic Astrophysics / 21

Transonic accretion flow with time-dependent boundary conditions in HARM.

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Accretion disks in High mass X-ray binaries (HMXB's) are mostly fed by the stellar wind from there companion star. These winds also affect the observed X-ray spectra arising from the hot coronal flow.
Cygnus X-1 and its companion star, HDE-226868 is one of such HMXBs. It is one of the brightest X-ray sources observed and shows the X-ray intensity variations in both the soft and hard X-rays. I will present my recent work on 2D numerical modeling using GRMHD code - HARM, replicating such focused, clumpy wind from the binary companion fed for accretion onto the black hole. We model an inviscid, non-magnetized, transonic accretion flow with a low angular momentum profile. I will discuss my prescribed time-dependent boundary conditions in this code and how it affects the hydrodynamics of the flow in the relativistic framework.

Relativistic Astrophysics / 75

Moving away from the Near-Horizon Attractor of the Extreme Kerr Force-Free Magnetosphere

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Force-free electrodynamics is a non-linear regime of Maxwell's equations capable to provide the minimal non-trivial level of description for pulsar and black hole magnetospheres. For this system to be hyperbolic it is necessary that the field is magnetically dominated, F^2=B^2-E^2>0. Despite its crucial role in explaining energy and angular momentum extraction from slowly spinning black holes (via the celebrated Blandford & Znajek mechanism) no force-free analytic solution, which is also magnetically dominated, is known in the highly spinning regime.
Any stationary and axisymmetric solution in the extreme Kerr background converges to a force-free attractor when the near-horizon extreme Kerr (NHEK) region is resolved. We use this attractor solution as a universal starting point for perturbing away from the NHEK region and show that at the second order in perturbation theory it is possible to find magnetically dominated magnetospheres around the extreme Kerr black hole.
A similar attractor solution emerges in the near-horizon near-extreme Kerr (near-NHEK) region of a nearly-extreme Kerr spacetime, thus providing a more sensible model for astrophysical settings.

Mixed - classical gravity / 53

Shadow of Naked Singularity

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Recent observation of the shadow of the Messier 87 (M87) galactic center by the Event Horizon Telescope (EHT) group has triggered a great interest to investigate the causal structure of spacetime around the galactic center. From the recent investigations on gravitational lensing, it is now established that the shadow is not the signature of a black hole alone, it can also be cast by timelike or nulllike naked singularities in the presence of a photon sphere. In my talk, I will show a naked singularity, even without the photon sphere, can cast a shadow. I will show some noble features of the shadow cast by timelike and nulllike naked singularities in the absence of the photon sphere. Those noble features of the shadows of nulllike and timelike naked singularities may help us to distinguish between black holes and naked singularities observationally.

Mixed - classical gravity / 34

BiGONLight: a new tool for light propagation in numerical relativity

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In the current new era for cosmological observations, much work is devoted in investigating the possibility of measuring new effects like the secular changes of optical observables (known as drift effects). In this context, the new bi-local geodesic operators (BGO) formalism of light propagation provides a unified framework in which it is possible to describe all possible optical phenomena like the standard lensing effects as well as the drifts effects or the cosmic parallax. I will show how the BGO formalism can be used to compute optical observables in numerically simulated spacetimes through its implementation in the BiGONLight package.

Mixed - classical gravity / 65

Self-gravitating tori around black holes: Bifurcation, ergoregions, and geometrical properties

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This talk is based on the paper "Self-gravitating perfect-fluid tori around black holes: Bifurcations, ergoregions, and geometrical properties" by W. Dyba, W. Kulczycki, P. Mach, Phys. Rev. D (2020).
We investigate numerical solutions of Einstein field equations corresponding to a stationary, axial symmetric spacetime containing a self-gravitating perfect-fluid torus rotating around a black hole. We assume that the gas is polytropic and moves according to the Keplerian rotation law. We have found a new type of bifurcation in the parameter space of solutions—for a given maximal density within the torus and fixed inner and outer radii, there can exist two solutions differing in the mass of the torus. This effect can be explained in geometrical terms—the inner volume of the massive torus can be much larger than the volume corresponding to the light one. In both cases we investigate the influence of the torus on the location of the innermost stable circular orbit (ISCO). The result, especially for the less massive branch of solutions, may have astrophysical applications for the estimates

of the accretion rate, for example during binary neutron star mergers. We have also investigated strong field effects appearing for the massive branch of solutions, in particular the occurrence of ergoregions with spherical and toroidal topologies. If time permits, I will also discuss preliminary results on the stability of the obtained solutions.

Mixed - classical gravity / 78

On the canonical energy of weak gravitational fields with a positive cosmological constant

Author: Tomasz Smołka[1]

Co-authors: Piotr T. Chruściel [2]; Jahanur Hoque

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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.

Mixed - classical gravity / 50

Prospects of Probing Dark Energy with eLISA: Standard versus Null Diagnostics

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Gravitational waves from supermassive black hole binary mergers along with an electromagnetic counterpart has the potential to shed 'light' on the nature of dark energy in the intermediate redshift regime. An accurate measurement of dark energy parameters at intermediate redshift is extremely essential to improve our understanding of dark energy, and to possibly resolve couple of tensions involving cosmological parameters. We present a Fisher matrix forecast analysis in the context of eLISA to predict the errors for three different cases: the non-interacting dark energy with constant and evolving equation of state (EoS), and interacting dark sectors with a generalized parametrization. In all three cases, we perform the analysis for two separate formalisms, namely, the standard EoS formalism and the model-independent null diagnostics using \textit{Om} parametrization for a wide range of fiducial values in both phantom and non-phantom regions, in order to make a comparative analysis between the prospects of these two diagnostics in eLISA. Our analysis reveals that it is wiser and more effective to probe null diagnostics instead of the standard EoS parameters for any possible signature of dark energy at intermediate redshift measurements like eLISA.

Gravitational Waves / 94

Multi-messenger astronomy including gravitational-wave

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A new exploration of the Universe has recently started through gravitational-wave observations. On August 17, 2017, the first observation of gravitational waves from the inspiral and merger of a binary neutron-star system by the Advanced LIGO and Virgo network, followed 1.7 s later by a weak short gamma-ray burst detected by the Fermi and INTEGRAL satellites initiated the most extensive world-wide observing campaign which led to the detection of multi-wavelength electromagnetic counterparts. Multi-messenger discoveries are revealing the enigmas of the most energetic transients in the sky, probing neutron-stars physics, relativistic astrophysics, nuclear physics, nucleosynthesis, and cosmology. The talk will give an overview of the astrophysical implications of the gravitational-wave and multi-messenger observations, the prospects and challenges of the current and future gravitational-wave detectors.

Gravitational Waves / **95**

Effective-one-body waveform from coalescing binaries: recent developments

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I will report on recent developments of TEOBResumS, an effective-one-body based waveform model for coalescing relativistic binaries. In particular, I will discuss: (i) spin-aligned quasi-circular binaries; (ii) spin-aligned eccentric binaries; (iii) hyperbolic encounters and dynamical capture.

Gravitational Waves / **96**

Tests of general relativity through the direct detection of gravitational waves

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The detection by LIGO and Virgo of gravitational waves from compact binary coalescences has given us access to the genuinely strong-field, dynamical regime of gravity, enabling tests of general relativity in the fully nonlinear domain. Moreover, the nature of gravitational waves can be tested by looking at the way they propagate over large distances. As the sensitivity of the detectors improves, it will soon also be possible to probe the nature of compact objects themselves. In the case of presumed black holes, are they really the Kerr black holes of general relativity, or even more exotic objects? Thus, key questions about gravity - possibly including quantum gravity - can finally be addressed through direct observation.

Gravitational Waves / **43**

On Canonical Formalisms in General Relativity

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The canonical formalism by Arnowitt, Deser and Misner has proven very efficient in the derivation of higher order post-Newtonian (PN) dynamics of compact binaries in general relativity (GR), also including bodies with spin. There is ongoing strong impact on the gravitational wave research, in particular through its offspring, the effective-one-body (EOB) approach. The complete 3PN spinless binary dynamics has been obtained in 2001 and the 4PN one in 2014, each for the first time. However, there are two other canonical formalisms in GR, the somewhat related one by Dirac with its famous maximal slicing condition and the less known one by Schwinger with which by Kibble, and this for the first time, the Dirac spin-1/2-field equations had become canonically implemented into GR in fully gauge symmetry-reduced form. In my talk the three canonical formalisms will be presented and compared to each other.

Gravitational Waves / 67

Gravitational Waves from a newly born accreting magnetar

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We study the spin-evolution and gravitational-wave luminosity of a newly-born magnetar with an initial spin period of 1 ms and having an inclination α between the magnetic moment axis and the rotation axis. Given any random initial choice for the inclination, we always find $\alpha \longrightarrow 90 \circ$ in a few milliseconds. As the star rotates under the influence of magnetic dipole radiation and the escaping neutrinos, the corotation radius exceeds the magnetospheric Alfvén radius and two columns of accreting matter are formed at the poles which eventually reach hydrostatic equilibrium with the outflow and settling matter on the stellar surface. Initially, the spin period is mostly affected by the neutrino luminosity but at later times, accretion makes the star spin-up rapidly. This object, located at 1 Mpc, emit gravitational waves with a strain h_c ~ 10^{-24} at kHz frequencies. Given the estimated sensitivities for the third generation gravitational-wave detectors, we find that such an object would be a potential target.

Gravitational Waves / 60

Freely falling bodies in standing wave spacetime

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The phenomena of standing waves are mostly studied in the context of mechanical or electromagnetic waves. In the context of General Relativity, the issue of how to define standing gravitational waves was addressed by Bondi and later by Stefani. We investigate an expanding universe filled with standing gravitational waves. We study how freely falling particles in this spacetime behave, namely, we investigate the geodesic equation and the geodesic deviation equation. We show that antinodes attract freely falling particles.

Cosmology / 85

Planck scale as a constant of integration

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I will discuss local field theories with global degrees of freedom. The oldest of them is the so-called unimodular gravity introduced by Einstein a century ago. In this theory the cosmological constant is not a constant of nature, but merely a constant of integration. This provides an ideal landscape or ensemble of theories giving a different view on the origin of naturalness issues in modern physics.

Cosmology / 86

Cosmic String Interpretation of NANOGrav Pulsar Timing Data

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The NANOGrav Collaboration has recently reported strong evidence for a stochastic common-spectrum process, which we interpret as a SGWB in the framework of cosmic strings. The possible NANOGrav signal would correspond to a string tension Gμ∈(4×10^{−11},10^{−10}) at the 68% confidence level, with a different frequency dependence from supermassive black hole mergers. The SGWB produced by cosmic strings with such values of Gμ would be beyond the reach of LIGO, but could be measured by other planned and proposed detectors such as SKA, LISA, TianQin, AION-1km, AEDGE, Einstein Telescope and Cosmic Explorer.

Cosmology / 87

Dynamically induced Planck scale and inflation in the Palatini formulation

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We study non-minimal Coleman-Weinberg inflation in the Palatini formulation of gravity in the presence of an R^2 term. The Planck scale is dynamically generated by the vacuum expectation value of the inflaton via its non-minimal coupling to the curvature scalar R. We show that the addition of

the R^2 term in Palatini gravity makes non-minimal Coleman-Weinberg inflation again compatible with observational data.

Cosmology / 49

Universe in a black hole with spin and torsion

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The conservation law for the total (orbital and spin) angular momentum of a Dirac particle in the presence of gravity requires that spacetime is not only curved, but also has a nonzero torsion. The coupling between the spin and torsion in the Einstein-Cartan theory of gravity generates gravitational repulsion at extremely high densities. We consider gravitational collapse of a spin-fluid sphere into a black hole. We show that a singularity is replaced with a nonsingular bounce if there is no shear. We also show that torsion and quantum particle production during contraction avoid a singularity even if shear is present. Particle production during expansion can generate a finite period of inflation and produce enormous amounts of matter. The resulting closed universe on the other side of the event horizon may have several bounces. Such a universe is oscillatory, with each cycle larger in size then the previous cycle, until it reaches the cosmological size and expands indefinitely. Our universe might have therefore originated from a black hole.

Cosmology / 15

Curved spacetime Effective Field Theory (cEFT) as a tool to investigate vacuum stability

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I would like to present application of the recently proposed curved spacetime Effective Field Theory (cEFT) to a problem of vacuum stability. To model the matter sector we used two scalar fields coupled through the Higgs portal type of interaction. Additionally, both of these fields were coupled non-minimally to gravity. This may be considered as a simplified model describing an interaction of the real part of the Higgs doublet with the heavy scalar dark matter. To tackle the problem of the false vacuum stability against spontaneous creation of the true vacuum bubble we firstly integrated out the heavy scalar and obtained cEFT for the light field. Then we investigated the influence of the higher order gravity mediated operators on vacuum stability. Results will be discussed in this presentation.
The presentation is based on the paper arXiv:2004.12327, that was written in collaboration with Z. Lalak and A. Nakonieczna.

Cosmology / 48

Generation of Z bosons in emission processes by neutrinos in early Universe

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Production of Z bosons in emission processes by neutrinos in the expanding de Sitter universe is studied. We use perturbative methods to investigate emission processes that are forbidden in flat spacetime electroweak theory by the energy and momentum conservation. The amplitude and probability for the spontaneous emission of a Z boson by a neutrino or an antineutrino are computed analytically, then we perform a graphical analysis in terms of the expansion parameter. Our results prove that this process is possible only for large expansion conditions of the early Universe. The total probability of the process is analysed and we explore the physical consequences of our results proving that in the Minkowski limit there is no emission of Z bosons by neutrinos. The limit of large space expansion when the expansion parameter is larger than the mass of the Z boson is also obtained and the results prove that in this limit the emission probability increase.

Cosmology / 31

Cosmological attractor approximation in Einstein-Gauss-Bonnet gravity

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We construct models with the Gauss-Bonnet term multiplied to a function of the scalar field leading to inflationary scenario. The consideration is related with the slow-roll approximation. The cosmological attractor approach gives the spectral index of scalar perturbations which is in a good agreement with modern observation and allows variability for tensor-to-scalar ratio. We reconstruct models with variability of parameters which allow to reproduce cosmological attractor predictions for inflationary parameters in the leading order of 1/N approximation in the Einstein-Gauss-Bonnet gravity.
The talk is based on the paper by E.O. Pozdeeva, Eur.Phys.J.C 80 (2020) 7,612 [arXiv:2005.10133 [gr-qc]].

Quantum Gravity and Quantum Cosmology / 91

What happens at the end of the evaporation of a black hole?

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What happens at the evaporation of a black of a black hole is not only still unclear, but also – contrary to what is sometimes claimed – relevant for the issue of unitarity in blackhole physics. I illustrate what we know about this physics. I show that the problem breaks into three distinct processes, to some extent independent: the quantum physics of the matter reaching the black hole center, the quantum physics of the spacetime region approaching the singularity itself, and quantum the physics of the horizon, as it shrinks towards the Planck scale. We have interesting indications on the first two, and tools to address the third, in particular using covariant loop quantum gravity. I

describe the possibility of a quantum tunnelling across the classical singularity into a white hole region, the matter-bounce at the stage called "Planck star" and the tunnelling of the horizon from black to white. I explain why there is no reason to expect Hawking radiation's entropy to follow a Page curve, and how information can be trapped in the large interior volume of a hole and reemitted at the white-hole/remnant stage.

Quantum Gravity and Quantum Cosmology / 93

Topology, coordinates, and fields in Causal Dynamical Triangulations

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Causal Dynamical Triangulations (CDT) is a background independent approach to quantum gravity which introduces a lattice regularization. The framework uses only geometric invariants without referring to any coordinate system.
One of its features is the ability to control the topology of the Universe. The introduction of toroidal spatial topology allows for a definition of hypersurfaces which can serve as reference frames used to construct a coordinate system.
In this talk, I will discuss how to define coordinates, via a classical scalar field, in a way that is invariant under the redefinition of the hypersurfaces.
I will show how the new coordinates give an insight into the geometric structure of configurations appearing in four-dimensional Causal Dynamical Triangulations.

Quantum Gravity and Quantum Cosmology / 39

Space of quantum states built over metrics of fixed signature

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A space of quantum states and an algebra of quantum observables are constructed over the set of all metrics of arbitrary but fixed signature, defined on a manifold. The construction is diffeomorphism invariant, and unique up to natural isomorphisms.

Quantum Gravity and Quantum Cosmology / 41

Finite Quantum Gravity

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In this talk, I will present the first construction of the theory of quantum gravity completely free of UV divergences. I will show the successful construction in the framework of quantum field theory of gravitational interactions. Moreover, I will relate the enhanced symmetry properties of this theory with fixed points of RG flow and ensuing quantum conformal invariance. The implications for the absence of classical GR-like singularities will be presented as well.

Quantum Gravity and Quantum Cosmology / 36

On the spectral dimensionality of quantum spacetimes

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The spectral dimension is one of definitions of the effective dimensionality of spacetime that is commonly applied to characterize quantum gravity models. A quite universal prediction is the dimensional reduction to 2 in the UV regime. The notion of spectral dimension can be seen as arising from properties of either a (fictitious) diffusion process or spectral geometry. In the latter context, there also exists the related notion of dimension spectrum. The application of both concepts may lead to various pitfalls; they are actually associated with the heat trace expansion, which is an important tool in quantum field theory. Furthermore, quantum spacetime is often described in terms of broadly understood noncommutative geometry, which requires even more care. It turns out that the spectral dimension and dimension spectrum complement each other, as can be illustrated with the use of two contrasting examples: the quantum sphere and κ-Minkowski spacetime, with different possible choices of Laplacians that determine their geometries. In the former case, we also observe curious oscillations of dimension in the UV regime (which could leave an imprint on the cosmic microwave background).

Quantum Gravity and Quantum Cosmology / 71

Loop quantum Schwarzschild interior and black hole remnant

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The interior of a Schwarzschild black hole is quantized by the method of loop quantum gravity. The Hamiltonian constraint is solved and the physical Hilbert space is obtained in the model. The properties of a Dirac observable corresponding to the Arnowitt-Deser-Misner mass of the Schwarzschild black hole are studied by both analytical and numerical techniques. It turns out that zero is not in the discrete spectrum of this Dirac observable. This supports the existence of a stable remnant after the evaporation of a black hole. Our conclusion is valid for a general class of schemes adopted for loop quantization of the mode

Quantum Gravity and Quantum Cosmology / 17

Quantum fate of generic gravitational singularity

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I will present quantum model of the dynamics underlying the Belinski-Khalatnikov-Lifshitz (BKL) scenario. The classical BKL scenario concerns generic singularity of general relativity. The quantum BKL scenario indicates that the gravitational singularity can be avoided by a quantum bounce. The latter presents a unitary evolution of considered gravitational system. It is fairly probable that quantum general relativity, to be constructed, would be free from singularities.

Quantum Gravity and Quantum Cosmology / 92

3d gravity and quantum groups

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It is well-known that quantum groups are relevant to describe the quantum regime of 3d gravity. They encode a deformation of the gauge symmetries (Lorentz symmetries) parametrized by the value of the cosmological constant. Such deformation might be perplexing from a classical picture since the action is defined in terms of plain/undeformed gauge symmetry. I would like to present here a novel way to derive/justify such quantum group deformation, starting from the classical gravity action.

98

Gravitational Entropy and the Second Law of Thermodynamics

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The identification of black hole event horizon area with entropy by Bekenstein and Hawking suggested a generalized second law of thermodynamics. This was later extended to cosmological horizons. However, there remain some deep unsolved problems about the validity of the generalized law in the cosmological case, and unanswered questions about whether a more comprehensive notion of gravitational entropy is required. These issues have important philosophical implications for the nature of physical law.

Beyond General Relativity / 83

Lessons for quantum cosmology from anti-de Sitter black holes

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Gravitational physics is arguably better understood in the presence of a negative cosmological constant than a positive one, yet there exist strong technical similarities between the two settings. These similarities can be exploited to enhance our understanding of the more speculative realm of quantum cosmology, building on robust results regarding anti-de Sitter black holes describing the thermodynamics of holographic quantum field theories. To this end, we study 4-dimensional gravitational path integrals in the presence of a negative cosmological constant, and with minisuperspace metrics. We put a special emphasis on boundary conditions and integration contours. The Hawking-Page transition is recovered and we find that below the minimum temperature required for the existence of black holes the corresponding saddle points become complex. When the asymptotic anti-de Sitter space is cut off at a finite distance, additional saddle points contribute to the partition function, albeit in a very suppressed manner. These findings have direct consequences for the no-boundary proposal in cosmology, because the anti-de Sitter calculation can be brought into one-to-one correspondence with a path integral for de Sitter space with Neumann conditions imposed at the nucleation of the universe. Our results lend support to recent implementations of the no-boundary proposal focusing on momentum conditions at the "big bang".

Beyond General Relativity / 13

Early evolutionary tracks of low-mass stars in modified gravity

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I will present how pre-main sequence and low-mass stars' (M<0.5 solar mass) can be a laboratory for constraining theories of gravity. We will discuss modified gravity impacts on their early evolution, such as Hayashi tracks and radiative core development, together with the measured quantities such as effective temperature, masses, and luminosities as well as fusion of light elements.

Beyond General Relativity / 84

Aspects of AdS/CFT at finite cut-off

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I will discuss the AdS/CFT correspondence with finite cut-off and TT-deformations of holographic conformal field theories. After introduction, I will present some recent results for the deformations of 2d conformal field theories on curved backgrounds and their holographic realization in Anti-de Sitter geometries in 3 spacetime dimensions.

Beyond General Relativity / 37

Covariant actions for bouncing cosmology in modified Gauss-Bonnet gravity theories

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Cyclic universes with bouncing solutions are candidates for solving the big bang initial singularity problem. Here I will look for bouncing solutions in the context of modified Gauss-Bonnet gravity theories whose field equations contain up to fourth-order derivatives of the metric tensor. In finding such bouncing solutions I will resort to an order reduction technique that reduces the order of the differential equations of the theory to second-order and thus enables one to find solutions which are perturbatively close to general relativity. I will also build the covariant effective actions of the resulting order reduced theories.

Beyond General Relativity / **51**

Canonical variational completion of 4D Gauss-Bonnet gravity

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We consider a recent proposal to obtain a finite contribution of second derivative order to the gravitational field equations in $D = 4$ dimensions from a renormalized Gauss-Bonnet term in the action. In previous works, it has been shown that the resulting field equations cannot be obtained as the Euler-Lagrange equations from a diffeomorphism-invariant action. Here we use techniques from the inverse calculus of variation as an independent confirmation that the suggested truncated Gauss-Bonnet field equations cannot be variational, in any dimension. For this purpose, we employ canonical variational completion, based on the notion of Vainberg-Tonti Lagrangian, which consists in adding a canonically defined correction term to a given system of equations, so as to make them derivable from an action. We find that in $D > 4$ the suggested field equations can be variationally completed, which yields a theory with fourth order field equations. In $D = 4$ the variationally completed theory diverges. Our findings are in line with Lovelock's theorem, which states that, in 4 dimensions, the unique second-order Euler-Lagrange equations arising from a scalar density depending on the metric tensors and its derivatives, are the Einstein equations with a cosmological constant.

This contribution is based on arXiv:2009.05459.

Beyond General Relativity / **58**

Neutrino oscillations in extended theories of gravity

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In this talk, I summarize the process of investigating neutrino oscillations within the framework of extended theories of gravity. Based on the covariant reformulation of Pontecorvo's formalism, the oscillation probability of neutrinos propagating in static spacetimes described by gravitational actions quadratic in the curvature invariants is evaluated. For the sake of simplicity, calculations are carried out in the two-flavor approximation. It is shown that the neutrino phase is sensitive to the violation of the strong equivalence principle. By way of illustration, I specialize the analysis to various extended models of gravity in order both to quantify such a violation and to understand how the characteristic free parameters of these models affect the neutrino phase. The possibility to fix new bounds on these parameters and to constrain extended theories of gravity is finally discussed.

Beyond General Relativity / 64

The Teleparallel version of Horndeski gravity

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Horndeski gravity is the most general scalar tensor theory, with a single scalar field, leading to second-order field equations and after the GW170817 it has been severely constrained. In this talk, I will present an analog of Horndeski's theory in the Teleparallel Gravity framework where gravity is mediated through torsion instead of curvature. It will be shown that, even though, many terms are the same as in the curvature case, we have much richer phenomenology in the teleparallel setting because of the nature of the torsion tensor. After this, I will show that by performing tensorial perturbations in this theory in a flat cosmological background, one is able to restore the severely constrained terms in standard Horndenski, creating an interesting way to revive Horndeski gravity. I will finalize my talk explaining about the PPN analysis of this model.

Mixed - extending gravity / 20

Asymptotic generalized extended uncertainty principle

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We present a formalism which allows for the perturbative derivation of the Extended Uncertainty Principle for arbitrary spatial curvature models. The leading curvature induced correction is proportional to the Ricci scalar evaluated at the expectation value of the position operator. By Born reciprocity this method can be equivalently applied in curved momentum space allowing for a general uncertainty principle or curved momentum space quantum mechanics.

Mixed - extending gravity / 68

Quantum fluctuations of the compact phase space cosmology

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In the recent article Phys. Rev. D 100, no. 4, 043533 (2019) a compact phase space generalization of the flat de Sitter cosmology has been proposed. The main advantages of the compactification is that physical quantities are bounded, and the quantum theory is characterized by finite dimensional Hilbert space. The purpose of this presentation is to discuss the extraction of semiclassical effects from this model by way of canonical effective methods. First, a brief review of canonical effective methods is given. Afterwards, we discuss the character of the semiclassical solutions of the compact phase space cosmological model. Finally, a relation between the behavior of the quantum fluctuations of the cosmological sector and the holographic Bousso bound is discussed

Mixed - extending gravity / 44

Computable Loop Quantum Gravity

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The full theory of LQG presents enormous challenge to create physical computable models. In this talk we will present the new modern version of Quantume Reduced Loop Gravity (QRLG). We will show that this framework provide an arena to study the full LQG in a certain limit, where the quantum computations are possible. We will analyze all the major step necessary to build this framework, how is connected with the full theory, its matematical consistency and the physical intuition behind It.

Mixed - extending gravity / 22

The kinetic gas universe - Lifting the Einstein Vlasov system to the tangent bundle

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In this talk I will present a new model for the description of a gravitating kinetic gas, by coupling the 1-particle distribution function (1PDF) of the gas directly to the gravitational field, lifted to the tangent bundle of spacetime. This procedure takes the influence of the velocity distribution of the kinetic gas particles on their gravitational field fully into account, instead of only on average, as it is the case for the Einstein-Vlasov system.

By using Finsler spacetime geometry I construct an action for the kinetic gas on the tangent bundle, which is added as matter action to a canonical Finslerian generalisation of the Einstein-Hilbert action. The invariance of the kinetic gas action under coordinate changes gives rise to a new notion of energy-momentum conservation of a kinetic gas in terms of an energy-momentum distribution tensor. The variation of the total action with respect to the spacetime geometry defining Finsler Lagrangian yields a gravitational field equation on the tangent bundle, which determines the geometry

of spacetime directly from the full non-averaged 1PDF. This equation can be regarded as generalisation of the Einstein-Vlasov system, which takes all features of the kinetic gas into account.

The talk will be based on the essay The Kinetic Gas Universe and the article Relativistic kinetic gases as direct sources of gravity.

Mixed - extending gravity / 47

Hairy black holes and the dark sector influence

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In this short talk I will briefly discuss the hairy black hole solutions obtained within Einstein-Maxwell-Scalar theory with so called box boundary conditions and the influence of dark sector fields on the modelled system. The phase diagram of the theory will be presented with the explanation of the influence of the hidden sector on the thermodynamics of particular phases (hairy black holes, boson stars, RN-like black holes). Finally I will show that dark matter in the presented model can significantly decrease the chance of the emergence of a hairy solution.