Research Training Group
Graduiertenkolleg
Models of Gravity

Spring Workshop 2021

21. – 25. June 2021

online

List of speakers:

- Jose Luis Blázquez-Salcedo (Complutense University of Madrid)
- Christian Böhmer (University College London)
- Beatrice Bonga (Radboud University, Nijmegen)
- Lucas Collodel (Uni Tübingen)
- Sam Dolan (University of Sheffield, UK)
- Betti Hartmann (University College London)
- Shokufe Faraji (ZARM, Uni Bremen)
- Helmut Friedrich (AEI, Golm)
- Torben Frost (ZARM, Uni Bremen)
- Sandro Goedtel (ZARM, Uni Bremen)
- Jan Hackstein (ZARM, Uni Bremen)
- Mourad Halla (ZARM, Uni Bremen)
- Sarah Kahlen (Uni Oldenburg)
- Wojciech Kulczycki (Jagiellonian University, Kraków)
- Edward Malec (Jagiellonian University, Kraków)
- Jan-Menno Memmen (ZARM, Uni Bremen)
- Carla Schriever (Uni, Oldenburg)
- Yuko Urakawa (KEK, Japan)
- Francesca Vidotto (Western University Ontario)
- Alexander F. Zakharov (BLTP, JINR, Dubna)

Abstracts:

Jose Luis Blázquez-Salcedo (Complutense University of Madrid)

Title: Traversable wormholes in Einstein-Dirac-Maxwell theory

Abstract:
In this talk we present results on traversable wormholes in Einstein-Dirac-Maxwell theory in four spacetime dimensions. We will start discussing the framework of the model, which includes two massive fermions in a singlet state, allowing for the construction of families of spherically symmetric asymptotically flat configurations. We will show that exact solutions are obtained in the case of ungauged, massless fermions. More general localized states are constructed numerically in the case of massive fermions. We will discuss the properties and features of these wormholes, such as their connection with extremal Reissner-Nordström black holes, Smarr relation, domain of existence, etc.

Christian Böhmer (University College London)

Title: Modified theories of gravity - foundations and models

Abstract:
In the first part of the talk I am discussing General Relativity, in particular its basic ingredients and its mathematical structure. This will naturally lead the way to consider various modifications or extensions of General Relativity, many of which have been studied recently. Next I will discuss modified gravity models based on generalised geometries and on actions no longer linear in curvature. The main part of the talk will discuss how these many different theories can be studied using a single unified approach which also shows the equivalence of some of these models. Boundary terms in the action will play a crucial role in establishing the equivalence between different theories. This setup will also allow us to discuss models where local Lorentz invariance can be broken and also models where local diffeomorphisms can be broken. In general this is done by introducing appropriate length scales.

Beatrice Bonga (Radboud University, Nijmegen)

Title: Resonances in black hole spacetimes

Abstract:
Resonances are ubiquitous in nature. In this talk, I will focus on resonances due to the interaction of two black holes orbiting a central massive black hole. Such tidal resonances will generically occur for EMRIs if nearby compact objects exist. By probing their influence on the phase of the EMRI waveform, we can in principle extract information about the environmental tidal field of the EMRI system, albeit at the cost of a more complicated EMRI waveform model. I will also describe mean motion resonances, which are a mechanism that can create the necessary conditions for tidal resonance to occur.

Lucas Collodel (Uni Tübingen)

Title: Circular Orbit Structure and Thin Accretion Disks around Kerr Black Holes with Scalar Hair

Abstract:
Thin accretion disks is a simple, yet robust, approach to probe and constrain different compact objects (and theories) with electromagnetic observations of X-ray and (hopefully in the future) light-UV binaries. The disk properties depend solely on the structure of equatorial circular geodesics in a particular spacetime, and it's therefore of utmost importance to understand all of its particular features. In this talk, we'll present some very distinct traits of Kerr Black Holes with Scalar Hair (KBHsSH) that arise from the combined bound system of a hole with an off-center, self-gravitating distribution of scalar matter. As opposed to the exterior region of Kerr, the metric functions don't behave monotonically and some assumptions we automatically assume by intuition fail to be true. As a consequence, for a good portion of the parameter space the thin disk approach breaks down either because: the orbital parameters become discontinuous; the ISCO is ill-defined; or there's a region with two prograde stable orbits. The otherwise regular solutions are used to construct thin disks, from which we extract the fluxes and luminosity and compare in batches of same normalized spin parameter. We argue that with additional observations this could be used to constrain the scalar charge of the system. Finally, we show that KBHsSH can have an energy conversion efficiency of more than 90 %.

Sam Dolan (University of Sheffield, UK)

Title: Black holes, classical fields and geometric optics

Abstract:
In this talk I will review some aspects of the absorption, scattering and propagation of fields (electromagnetic, gravitational and neutrino) by 4D black hole spacetimes (Schwarzschild, Reissner-Nordstrom and Kerr) and by compact bodies without a horizon (e.g. neutron stars). I will cover quasinormal modes; bound states; superradiance; the superradiant instability; and the conversion of electromagnetic waves into gravitational waves by a charged black hole (the Gertsenshtein effect). I will make use of the geometric-optics approximation to describe wave propagation at short wavelengths in terms of bundles of geodesics.

Betti Hartmann (University College London) and **Carla Schriever** (Uni Oldenburg)

Title: Ayn Rand (Philosopher) & Maria Goeppert-Mayer (Physicist)

Abstract:
The contributions of women to the advance of knowledge and thought have been and are still marginalized. This is in particular true for physics and philosophy, two disciplines that have always had a close connection and are traditionally male dominated. In this talk we will discuss two women that have made fundamental contributions to physics and philosophy, respectively, in the middle of the 20th century: Ayn Rand, a Russian-born American philosopher, and Maria Goeppert-Mayer, a German-

born American nuclear physicists and the second woman to win the Nobel prize in physics. We will discuss the impact of their contributions and will also try to demonstrate - using their examples - how the paths of women's lives have been and are still influenced by social norms.

Shokufe Faraji (ZARM, Uni Bremen)

Title: Properties of accretion disks with quadrupole

Abstract:
tbd

Helmut Friedrich (AEI, Golm)

Title: On our early past and late future

Abstract:
In this talk I shall discuss results on the asymptotic behaviour of solutions to the Einstein-Lambda-matter equations and possible consequences they may have for the early past and late future of our cosmos.

Torben Frost (ZARM, Uni Bremen)

Title: Gravitational lensing by charged accelerating black holes

Abstract:
Current astrophysical observations show that on large scale the Universe is electrically neutral. However, locally this may be quite different. Black holes enveloped by a plasma in the presence of a strong magnetic field may have acquired a significant electric charge. We can also expect that some of these charged black holes are moving. Consequently to describe them we need spacetime metrics describing moving black holes. In general relativity such a solution is given by the charged C-de Sitter-metric. In this talk we will assume that it can be used to describe moving charged black holes. We will investigate how to observe the electric charge using gravitational lensing. First we will use elliptic integrals and functions to solve the geodesic equations. Then we will derive lens equation, travel time and redshift. We will discuss the impact of the electric charge on these observables and potential limitations for its observation.

Sandro Goedtel (ZARM, Uni Bremen)

Title: Bose-Einstein condensate with Yukawa-type gravitational selfinteraction

Abstract:
The theories of Newtonian and Einsteinian gravity are extremely powerful in describing the

macroscopic world. On the other side, however, we still do not have a widely accepted description of short-range gravity. Nowadays many theories going beyond the standard model predict deviations to Newtonian gravity, commonly in the form of a Yukawa-like potential. Since then different experiments have found upper boundaries for the strength and the range of this deviation. However, most of the experiments are focused on a test body in an external gravitational field. In this talk we present a model for a Bose-Einstein condensate which particles interact via a Newton and a Yukawa potential. In a selfconsistent manner, we determine the influence of such gravitational potentials onto the condensate. We derive the changes in the width of the cloud and the frequencies of the collective oscillations. With this we are able to set boundaries for the parameters of the Yukawa potential and compare them to the results of current experiments.

Jan Hackstein (ZARM, Uni Bremen)

Title: Photon region and shadow in a spacetime with a quadrupole moment

Abstract:
A black hole's shadow is expected to deform under the influence of an external gravitational field caused by matter present in its vicinity. This talk aims to characterise the distortion of a Schwarzschild black hole shadow due to a non-zero quadrupole moment c2 by qualitatively investigating the behaviour of light rays close to the black hole horizon. In particular, the numerical investigation in the meridional plane for 1 >> c2 > 0 finds four non-circular closed geodesics and their neighbouring geodesics exhibit chaotic behaviour that is not present in the undistorted Schwarzschild spacetime. The black hole shadow is therefore approximated by restricting the observational setup accordingly. In that case, the black hole shadow's eccentricity indicates a prolate deformation for static observers. The photon sphere in the Schwarzschild spacetime deforms into a photon region with a crescent-shaped projection on the meridional plane. Furthermore, the resulting boundary curve of the black hole shadow is visualised.

Mourad Halla (ZARM, Uni Bremen)

Title: A Morse-theoretical analysis of gravitational lensing by rotating traversable wormholes

Abstract:
Consider, in the domain of wormhole, a point p (observation event) and a timelike curve γ (worldline of light source). We prove that for infinitely many positive integers κ there is a past-pointing lightlike geodesic λ_κ of Morse index κ from p to γ, hence an observer at p sees infinitely many images of γ. We will show that in the spacetime of a rotating traversable wormhole the occurrence of infinitely many images is intimately related to the occurrence of centrifugal-plus-Coriolis force reversal.

Sarah Kahlen (Uni Oldenburg)

Title: Quasinormal modes of spherically symmetric black holes in Einstein-Maxwell-scalar theory

Abstract:
In Einstein-Maxwell-scalar (EMs) theory, gravity is coupled to a Maxwell field and a scalar field, with some function coupling the two fields. The choice of that function strongly influences the properties of the resulting black hole solutions. In the talk, static spherically symmetric EMs black hole solutions for two different coupling functions are dealt with. Firstly, it is shown that the two functions lead to black hole solutions with quite different properties. The focus then lies on the quasinormal modes, the eigenvalues of the linearly perturbed field equations, that can be categorized into axial and polar modes. Some of the numerically obtained modes for both functions are shown, and it is demonstrated how the presence of the scalar field influences different types of modes and breaks the isospectrality between polar and axial perturbations, which e.g. holds for Reissner-Nordström black holes in Einstein-Maxwell theory.

Wojciech Kulczycki (Jagiellonian University, Kraków)

Title: Rotating general-relativistic tori: on numerics and programming

Abstract:
We have been investigating stationary axially-symmetric black-hole–disk systems, where the disk is self-gravitating. In such systems due to lack of analytical solutions all results have to be numerical. Recently, we analysed disks described by the equation of state that is a combination of the DD2 and Timmes-Swesty equations of state and discovered the existence of bifurcation of solution. However, obtaining of solutions on one of the bifurcation branches was tricky on a technical level. In my talk I would like to present the numerical scheme we applied. In particular, I would like to focus on the trick we used to obtain the aforementioned bifurcation.

Edward Malec (Jagiellonian University, Kraków)

Title: Rotating general-relativistic tori: numerical results, bifurcation and a challenge for mathematics

Abstract:
I shall report recent results on stationary configurations that describe rotating fluid disks around spinless or spinning black holes. These are self-contained models, with the selfgravity being included. New rotation laws are applied; they comprise, in particular, the general-relativistic version of the familiar Keplerian rotation law. Numerical investigation suggests the emergence of bifurcation. All, that is known about such systems, comes from numerics there are no analytical results.

Jan-Menno Memmen (ZARM, Uni Bremen)

Title: Geometrically thick tori around compact objects with a quadrupole moment

Abstract:
We study geometrically thick perfect-fluid tori with constant specific angular momentum, so-called

'Polish doughnuts', orbiting deformed compact objects with a quadrupole moment. More specifically, we consider two different asymptotically flat, static and axisymmetric vacuum solutions to Einstein's field equation with a non-zero quadrupole moment, the q-metric and the Erez–Rosen spacetime. It is our main goal to find features of Polish doughnuts in these two spacetimes which qualitatively distinguish them from Polish doughnuts in the Schwarzschild spacetime. As a main result we find that, for both metrics, there is a range of positive (Geroch–Hansen) quadrupole moments which allows for the existence of double tori. If these double tori fill their Roche lobes completely, their meridional cross-section has the shape of a fish, with the body of the fish corresponding to the outer torus and the fish-tail corresponding to the inner torus. Such double tori do not exist in the Schwarzschild spacetime.

Yuko Urakawa (KEK, Japan)

Title: Signature of axion dark matter through gravitational messenger

Abstract:
Axion like particle is a compelling candidate of dark matter. Furthermore, exploring axion like particles (ALPs) provides a unique window to explore beyond standard model physics such as string theory. To identify an ALP as dark matter, we need to look for a unique signal which enables us to distinguish it from other dark matter candidates. In this talk, I will explain new methods to detect the imprint of ALPs through gravitational messenger, including observations of nHz gravitational waves with circular polarization.

Francesca Vidotto (Western University Ontario)

Title: Black Holes and Quantum Gravity: theory and possible observations

Abstract:
Black Holes are a privileged object to study quantum-gravitational effects: these can manifest at different locations, such as the center or at the horizon of a black hole, or even outside, and they can manifest at different epochs of the black-hole lifetime, including a potential remnant phase. In this talk I discuss the different cases. I highlight how Loop Quantum Gravity, as a non-perturbative theory, provides the tools to carry some specific computations, removing the central singularity and allowing the black hole to "decay" in a white hole. I conclude by discussing the possible observational signatures that quantum-gravitational phenomena can give, including consequences for cosmology and the nature of dark matter.

Alexander F. Zakharov (BLTP, JINR, Dubna)

Title: Observations of bright stars near the Galactic Center and observations of shadows at Sgr A* and M87* as tools to test gravity theories

Abstract:
General relativity (GR) was remarkably confirmed in many experiments and observations. However, a number of alternative theories have been proposed. In 2019 the Event Horizon Telescope (EHT) collaboration presented the first reconstruction of the shadow in M87*. The evaluated shadow size is in accordance with GR predictions but assuming some alternative theories of gravity one predicts other sizes for shadows. It gives an opportunity to constrain parameters of these alternative theories based on estimations of shadow size in M87*. Observations of bright stars near the Galactic Center demonstrated that the preferable model for the Galactic Center is the supermassive black hole. These observations with VLT and Keck telescopes got a high recognition among a scientific community and R. Genzel (VLT) and A. Ghez (Keck) were awarded the Nobel prize in physics in 2020. We discuss opportunities to evaluate parameters of the supermassive black hole and extended mass distribution from these observations. Similarly, these observations give a possibility to find constraints on alternative theories of gravity such as *f(R)* theory, Yukawa gravity and theories with massive graviton. Graviton mass limits found with the approach is comparable constraints obtained with other techniques including gravitational wave observations with LIGO—Virgo detectors. Our constraints on graviton from trajectories of bright stars near the black hole at the Galactic Center mass was included in PDG reviews (2019 update, 2020, 2021 update).