Research Training Group
Graduiertenkolleg
Models of Gravity

Newsletter – June 2019

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Recent PhDs

Recently three students of the RTG obtained their PhD:

- Mandy Wygas, Bielefeld (18.02.19)
- Lucas Gardai Collodel, Oldenburg (20.02.19)
- Zahra Altaha Motahar, Oldenburg (22.02.19)

New PhD Student

Mourad Halla started his PhD at ZARM on 1.2.19. He works with Volker Perlick.

Neutron stars in Scalar Tensor Theories of Gravity

Zahra Altaha Motahar

Various theoretical and experimental observations in cosmology indicate that General Relativity (GR) should be modified in the strong regime. Neutron stars represent valuable astrophysical laboratories to investigate various aspects of gravity. In the course of my doctoral research I worked on Neutron stars in Scalar Tensor Theories of Gravity (STT). My research projects focus on computing the properties of static and slowly rotating scalarized neutron stars as well as the axial Quasi-Normal Modes (QNMs) of these models.

We investigate the effect of scalarization on static and slowly rotating neutron stars for a large variety of realistic equations of state, including pure nuclear matter, nuclear matter with hyperons, hybrid nuclear and quark matter, and pure quark matter. We discover that the onset and the magnitude of the scalarization are strongly correlated with the value of the gravitational potential at the center of the star. In the process of these studies we achieved the solutions employing various equations of state for the models we were working with. We could extend and confirm universal relations between the scaled moment of inertia and compactness for the massless scalarized neutron stars beside the GR solutions. Investigating universal relations is essential since these relations are considered to be to a large extent independent of the employed equation of state (EOS) for the neutron star's matter composition. This is an extended version of known *I-C* universal relations since we included nuclear matter, hyperon and hybrid EOSs.

When two compact objects in a binary system merge to either a neutron star or a black hole, they emit gravitational waves. The complete waveform of detected gravitational waves has a typical sequence of phases, consisting of inspiral, merger and ringdown. The ringdown of the resulting compact object after the merger is dominated by its quasi-normal modes. In this research project, we first compute the axial QNMs of static neutron stars in massless STT. As we are interested in investigating universal relations of neutron stars models, we employ various realistic equations of state, including nuclear, hyperonic and hybrid matter and in particular three new EOSs with a first order hadron-quark phase transition. We illustrate our models in several plots showing the fundamental curvature modes for the massless scalarized neutron star solustions comparing with the GR models. We find that the frequency of the modes and the damping time are reduced for the scalarized neutron stars.

Although the effect of spontaneous scalarization of neutron stars can be very large, binary pulsar observations and gravitational wave detections significantly constrain the massless STT. This restriction on massless STT motivates us to extend our studies to the case of massive scalar field which can not be restricted by the current observations, resulting in a large deviation of a massive scalarized solutions from pure GR. With the fixed coupling constant and massive scalar field, we compute the physical properties of our neutron stars model for different magnitude of self interacting term. As the self interaction additionally suppresses the massive scalar field, the effect of scalarization decreases by increasing the value of the self interaction parameter. We extend and confirm several universal relations including the universal relations for QNMs known in GR to the wide range of realistic EOS for scalarized neutron stars. We confirm the universality of the scaled frequency and damping time in terms of the scaled moment of inertia as well as compactness for neutron stars with and without scalarization.

Upcoming events

RTG Colloquia

05.06.19: Uni Bielefeld

06.11.19: Uni Oldenburg

04.12.19: Uni Hannover

05.02.20: ZARM, Bremen

RTG Workshops

25.-27.09.19: Uni Oldenburg

Other

03.06.19: PhD Defense of Christian Knoll

13.06.19: Habilitation colloquium of Dr. Eva Hackmann

Publications

M. M. Wygas, I. M. Oldengott, D. Bödeker and D. J. Schwarz, *Cosmic QCD Epoch at Nonvanishing Lepton Asymmetry*, Phys. Rev. Lett. 121 (2018) no.20, 201302

J. M. Pawlowski and D. Stock, *Quantum-improved Schwarzschild-(A)dS and Kerr-(A)dS spacetimes*, Phys. Rev. D 98 (2018) no.10, 106008

E. Hackmann and A. Dhani, *The propagation delay in the timing of a pulsar orbiting a supermassive black hole*, Gen. Rel. Grav. 51, no. 3, 37 (2019), Editor's Choice

J. L. Blázquez-Salcedo and C. Knoll, *Solutions of the massive Dirac equation in the near-horizon metric of the extremal five dimensional Myers-Perry black hole with equal angular momenta*, Phys. Rev. D **99** (2019) no.2, 024026

C. A. P. Bengaly, T. M. Siewert, D. J. Schwarz and R. Maartens, *Testing the standard model of cosmology with the SKA: the cosmic radio dipole*, MNRAS, 486, Issue 1 (2019) 1350-1357

J. L. Blázquez-Salcedo, C. Knoll and E. Radu, *Boson and Dirac stars in $D \geq 4$ dimensions*, Phys. Lett. B 793, 161 (2019)

Gravitational waves in conformal gravity

Patric Hölscher

The theory of general relativity (GR) explains gravitational phenomena with great success on distance scales of the Solar System. However, GR is a classical field theory which cannot be consistently combined with quantum mechanics and thus needs to be modified at the Planck scale. Besides that, on galactic scales GR cannot explain the rotation curves of spiral galaxies without assuming a large amount of unknown and invisible substance called dark matter, which has not been directly detected yet. Likewise, the lack of a consistent explanation of the accelerated expansion of the Universe within GR is known as the cosmological constant problem. A possible way to overcome these shortcomings is to modify the theory of gravity.

In my PhD project we studied fourth-order derivative conformal gravity (CG) models as promising candidates. In particular, we analyzed gravitational radiation in these models, which are invariant under local Weyl transformations, meaning that physics is independent of rescalings of spacetime intervals. Moreover, CG models are renormalizable and thus could solve the quantum gravity problem.

CG models are based on a unique action for gravity and only differ by the choice of the matter content, the coupling constants and their signs. The linearized field equations describe, in addition to the massless graviton in GR, a massive propagating spin-2 graviton. We derived the instantaneous power radiated from an idealized compact binary system and applied our results to the indirect detections of gravitational waves prior to the measurements of the LIGO/VIRGO Collaboration. If the mass of the massive graviton is large, CG reduces to GR and as expected the trajectories of binary systems are in agreement with the data. However, in the case of a small graviton mass the decrease of the orbital period is much smaller than in GR, so we conclude that it cannot explain the decay of the orbital period by gravitational radiation. Nevertheless, these results do not rule out CG models with a small mass completely, because we only demonstrated that much less energy, compared to GR, is transported to the far field of the source. But the energy lost by the system could be stored in the near field by some mechanism.

To close this loophole, we used the direct measurements of gravitational waves from the LIGO/VIRGO Collaboration to test CG models in the late inspiral phase. We calculated the chirp of the frequency and the waveform right before the merger phase. The result is that for a small graviton mass CG models cannot explain the chirp signal for any parameter combination since the amplitude of gravitational waves decreases as coalescence is approached. For a large graviton mass no significant deviation from the GR result could be found, because modifications are strongly suppressed on the relevant distance scales. Thus, predictions are in agreement with the LIGO/VIRGO observations and lead to the same chirp masses and distance estimates as in GR.

In summary, we can say that CG with a small graviton mass has been ruled out by our results. But CG with a large graviton mass represents an interesting candidate for a renormalizable theory of gravity.

Publications

J. L. Blázquez-Salcedo and C. Knoll, *Quasinormal modes of Dirac spinors in the background of rotating black holes in four and five dimensions*, Class. Quant. Grav. 36 (2019) no.10, 105012

P. Hölscher, *Gravitational Waves and Degrees of Freedom in Higher Derivative Gravity*, Phys. Rev. D 99 (2019) no.6, 064039

P. Hölscher and D. J. Schwarz, *Gravitational waves from inspiralling compact binaries in conformal gravity*, Phys. Rev. D 99 (2019) no.8, 084005

M. Minkov, M. Pinkwart and P. Schupp, *Entropy methods for CMB analysis of anisotropy and non-Gaussianity*, Phys. Rev. D 99, no. 10, 103501 (2019)

I. M. Oldengott, G. Barenboim, S. Kahlen, J. Salvado and D. J. Schwarz, *How to relax the cosmological neutrino mass bound*, JCAP 2019, no. 04, 049 (2020)

Z. Altaha Motahar, J. L. Blázquez-Salcedo, D. D. Doneva, J. Kunz and S. S. Yazadjiev, *Axial quasi-normal modes of scalarized neutron stars with massive self-interacting scalar field*, Phys. Rev. D 99, 104006 (2019)

J. L. Blázquez-Salcedo, Z. Altaha Motahar, D. D. Doneva, F. S. Khoo, J. Kunz, S. Mojica, K. V. Staykov and S. S. Yazadjiev, *Quasinormal modes of compact objects in alternative theories of gravity*, Eur. Phys. J. Plus 134, no. 1, 46 (2019)

F. Hajkarim, J. Schaffner-Bielich, S. Wystub and M. M. Wygas, *Effects of the QCD Equation of State and Lepton Asymmetry on Primordial Gravitational Waves*, Phys. Rev. D 99, no. 10, 103527 (2019)

Networking at the networking workshop

Claus Lämmerzahl

In the first funding period we had a networking workshop in Bremen with the Research Training Group "Quantum and Gravitational Fields" from the University of Jena. The emphasis of the workshop back then laid on theoretical developments. This time we had our Networking Workshop together with the Research Training Group associated with the Hannover Collaborative Research Center "Relativistic Geodesy", where some of us are also members, as well as with the International Max Planck Research School at the Max Planck Institute for Gravitational Physics located in Golm and Hannover. Accordingly, the main topics covered at this workshop were geometry, general relativity, gravitational waves, geodesy – experimentally as well as theoretically.

Contributions from our RTG came from Jutta Kunz on Neutron Stars, Volker Perlick on gravitational lensing, Jose Blasquez on quasinormal modes, Sven Herrmann on an improved test of the gravitational redshift, Audrey Trova on charged accretion disks, and Claus Lämmerzahl on new aspects in general relativistic geodesy.

The workshop started with an introduction by Karsten Danzmann emphasizing that all young doctoral researchers and postdocs are the leading physicists of the future and that now it is the time to make contact with each other, what will help ones career and will last a life long. After we were thus brought into the right mood, the lectures began.

Each lecture had 1.5 h slot. The lectures started at 9 in the morning, then there were two parallel lectures (one introductory and one more specialized topic) and after lunch there was another lecture. After the coffee and cake break there was a slot for asking questions and to discuss issues. However, the true highlight of each day was the real networking after dinner in the bowling bar.

The environment in Fintel at the Lüneburger Heide was superb. It was impossible to reach the hotel with public transportation, but it was equipped with everything we needed: a nice seminar room, good food and drinks, nice housing and an endless heathland for long walking tours.

We had the impression that everybody was happy with the workshop.

Publications

L. G. Collodel, B. Kleihaus and J. Kunz, *On the Structure of Rotating Charged Boson Stars*, arXiv:1901.11522

A. K. Chatterjee, K. Flathmann, H. Nandan and A. Rudra, *Analytic solutions of the geodesic equation for Reissner-Nordström (Anti-) de-Sitter black holes surrounded by different kinds of regular and exotic matter fields*, arXiv:1903.11878

E. Boffo and P. Schupp, *Deformed graded Poisson structures, Generalized Geometry and Supergravity*, arXiv:1903.09112

C. Hoffmann, T. Ioannidou, S. Kahlen, B. Kleihaus and J. Kunz, *Wormholes Immersed in Rotating Matter*, arXiv:1904.03032

M. Pinkwart, P. Schupp and D. J. Schwarz, *Linking multipole vectors and pseudoentropies for CMB analysis*, arXiv:1905.01176

Final workshop of the QSpace COST action

Eugenia Boffo

During the 11-15 of February the QSpace COST action final workshop was held in the Comenius University in Bratislava.

Before starting the report on that very inspiring and fruitful meeting, it is worth spending a few words explaining explain what a COST action is and what the Qspace COST action investigated in particular.

A COST action is an European funded research network, connecting several different European countries; in particular the East European ones are usually encouraged to join. The MP1405 QSpace (short form for "quantum structure of spacetime") started four years ago, and aimed at investigating the quantum properties of spacetime by considering it a noncommutative geometry (NCG) at the Planck scale rather than keeping the geometry smooth at that tiny length.

The research core consisted in three groups responsible for 1. studying phenomenological models of NCG including the Standard Model of particle physics and cosmology, 2. constructing new tools for the study of NC structures, and 3. extending NCG to models of gravity. Two of our RTG Models of Gravity PIs were directly involved in the COST action: Olaf Lechtenfeld was chairing the commission responsible to set up cross-meetings between the working groups and short term scientific missions, while Peter Schupp was vice-chair of the commission responsible for the gender and outreach activities.

In the years, the QSpace action organized many successful training schools for students, meetings, workshops and outreaching activities.

The Slovakian workshop in February featured the participation of some remarkable physicists, amongst those surely outstood sir Roger Penrose from Oxford, who discussed his latest advances in the twistor theory proposed by himself in the late '60ies and also gave a public lecture in the overcrowded lecture hall on the Hawking points in the CMB.

We had the chance to hear the newest results of many other scientists and young researchers, in particular Petr Hořava who discussed naturalness and the multicritical universe, Sergio Ferrara with his conformal supergravity and Ali Chamseddine who presented the noncommutativity of the Standard Model.

The meeting was accompanied by some collateral public events. Apart from the already mentioned public lecture by Penrose, another one was the exhibition "Women of Mathematics" created by Sylvie Paycha, mathematician herself, who wanted to portray women in their job and give them voice on their personal thoughts on the difficulties in the management of their careers and personal lives. The exhibition is portable and has already been displayed many other times across the entire world; on the dedicated website womeninmath.net the interested reader can find more about it.

Another entertaining event was the round table discussion in which Hořava, Penrose, Sakellariadou, Grosse and Ferrara debated on the leading principles for their research and on which of these they would be ready to renounce in the pursue of the quantum theory of gravity.

The recordings of the public lecture and of the round table, as well as the slides of the presentations and some pictures are available at the webpage of the conference qspace19.fmph.uniba.sk.

The high quality of the scientific contributions made the time in Bratislava unforgettable, however most of all it was extremely interesting to touch with hands what it really implies, for a group of scientists, to interface with the European institutions in order to be supported in their work.