Zentrum für angewandte Raumfahrttechnologie und Mikrogravitation
Center for Applied Space Technology and Microgravity

ZARM
Universität Bremen
Am Fallturm
28359 Bremen
Germany

3rd GIF workshop on "Exploration of Electrodynamics"

17 June to 20 June 2013, ZARM, Universität Bremen

Funded by the German-Israeli Foundation (GIF)

Organisation: Claus Lämmerzahl (ZARM, U Bremen)
Volker Perlick (ZARM, U Bremen)

The talks should be not more than 45 minutes. The rest of the time is for discussion.

Monday, 17 June (Room 1280)

09:00 F.W. Hehl (Cologne): Maxwell, Heaviside, Hertz: some historical remarks on the emergence of the Maxwell equations

10:00 A. Favaro (Cologne): Electromagnetic media with no Fresnel (dispersion) equation and novel jump (boundary) conditions

11:30 J. Gratus (Lancaster): Conservation laws and stress-energy-momentum tensors for systems with background fields

14:00 D. Giulini (ZARM): Poincaré stresses and classical electron models

15:00 E. Radu (Oldenburg): Higher dimensional black objects with nonstandard horizon topology: including the gauge fields

16:30 F. Gronwald (Hamburg): Engineering electromagnetics: Solving the Maxwell equations in the presence of complex engineering systems

17:30 Guided tour of the drop tower

Tuesday, 18 June (Room 1280)

09:00 P. Schupp (Jacobs): TBA

10:00 Ch. Pfeifer (Hamburg): Finsler spacetime dynamics

11:30 S. Abdolrahimi (Oldenburg): Distorted five-dimensional electrically charged black hole

14:00 N. Guerlebeck (ZARM): Dipole layers in curved spacetimes

15:00 D. Philipp (ZARM): Photon accumulation around black holes

16:30 E. Hackmann (ZARM): Motion of test particles in a regular black hole spacetime

17:30 Y. Itin (JCT): Which geometry is predicted by the electromagnetic waves?

Wednesday, 19 June (Room 1730)

09:00 T. Futamase (Tohoku): A new approximation for non-linear growth of dark matter perturbation and its power spectrum

10:00 D. Puetzfeld (ZARM): Motion of test bodies in theories with nonminimal coupling

11:30 U. Geppert (DLR Bremen): Pulsars and magnetars: Electromagnetic interactions inside and outside neutron stars

14:00 T. Scarr (Jerusalem): Time dilation and velocity and acceleration transformations in a uniformly accelerated frame

15:00 Y. Friedman (JCT): Digitization of the harmonic oscillator at high frequencies

Thursday, 20 June (morning: Room 1730, afternoon: Room 1280)

09:00 J. Steinhoff (ZARM): Action principles for extended objects in gravitational and electromagnetic fields

10:00 V. Perlick (ZARM): Self-force in Bopp-Podolsky theory

11:30 Y. Obukhov (Moscow): Electromagnetic energy and momentum in complex media

14:00 A. Grenzebach (ZARM): Lensing effects of charged black holes

15:00 C. Lämmerzahl (ZARM): G

16:30 Ch. Lienau (Oldenburg): Realizing strong electric fields

17:30 Y. Itin (JCT): Light propagation in anisotropic and skewon media

How to reach ZARM:

From the airport or from the central station: Take tram line 6 towards "Universität". Tickets (2.40 EUR) can be purchased from a vending machine inside the tram. Leave the tram at the final stop "Klagenfurter Strasse". The drop tower is a few steps away.

From Hotel Horner Eiche: Turn left, cross Lilienthaler Heerstrasse and the tram line. On the other side, there is a bus stop. Take bus 31 towards "Nedderland". You can buy tickets (2.40 EUR) from the driver. Leave the bus at the third stop "Linzer Strasse". The drop tower is a few steps ahead.

Titles and abstracts:

Shoreh Abdolrahimi (Oldenburg):

Distorted five-dimensional electrically charged black hole

In this talk we construct a new static black hole solution of the Einstein-Maxwell equations which admits an R1* U(1)* U(1) isometry group. This solution represents how the distortion generated by a static, axisymmetric and **neutral** electrically charged distribution of external matter affects a five-dimensional Reissner-Nordströom black hole. The inner (Cauchy) horizon remains regular for such a distortion and there exists a certain duality transformation between the inner and the outer horizons. We illustrate the effect of distortion on the curvature of the horizons and the maximal proper time of free fall from the outer to the inner horizon on the example of dipole-monopole and quadrupole-quadrupole distortion fields. The maximal proper time of free fall from the outer to the inner horizons can be shortened. The product of the inner and outer horizon areas doesn't change under the effect of the distortion and remains proportional to the electric charge

Alberto Favaro (Cologne):

Electromagnetic media with no Fresnel (dispersion) equation and novel jump (boundary) conditions

(joint work with Ismo Lindell, Espoo, Finland)

At a boundary that separates two insulators, the components of the electric field strength E and of the magnetic field excitation $\mathcal{H}$ parallel to the interface are continuous; moreover, the same is true for the components of the magnetic field strength B and of the electric field excitation $\mathcal{D}$ that are perpendicular to the interface. Because these jump conditions are an immediate consequence of Maxwell's equations, they are valid for all electromagnetic materials [Y. Itin, Ann. Phys. (NY) 327:359, 2012]; in the statement above, electric conductors were ruled out as a matter of simplicity. Numerous recent works discuss further jump conditions, whose role in the foundations of electrodynamics is secondary, but which have unique technological properties. For example, the boundary separating a perfect electromagnetic conductor (PEMC) and vacuum can act as a twist polariser. More in detail, for a specific choice of the key material parameter, the electric field of a wave being reflected off the interface is totally cross-polarised [I.V. Lindell and A. Sihvola, J. Electromagn. Waves Appl. 19(7):861, 2005]. Another possibility is to require that the components of the magnetic field strength B and of the electric field excitation $\mathcal{D}$ orthogonal to the interface vanish. Such $\mathcal{D}B$ jump conditions can be used to achieve invisibility to the monostatic radar, whose transmitter and receiver are located at the same point. More in detail, by engineering an appropriate material coating, it is possible to reduce the back-scattering cross-section of any object that is endowed with certain symmetries [I.V. Lindell, A. Sihvola, P. Ylä-Oijala, and H. Wallén. IEEE Trans. Antennas Propag. 57(9):2725, 2009]. The PEMC and various materials that give rise to the $\mathcal{D}B$ jump conditions share an interesting property: the Fresnel equation, which describes how light propagates in these and in all dispersionless media, subject to the validity of geometrical optics, is found to be satisfied for any choice of wave-covector. We attempt a systematic investigation of those material classes that exhibit the property just mentioned. Strong evidence is put forward that only three types of local and linear material exist whose Fresnel equation is satisfied trivially. In particular, we show that taking the inverse of the electromagnetic response tensor does not lead to new solutions, as appropriate. Further information is provided in the article [I.V. Lindell and A. Favaro, Prog. Electromagn. Res. B, 51:269, 2013].

Yaakov Friedman (Jerusalem):

Digitization of the harmonic oscillator at high frequencies

The Harmonic Oscillator serves as a model for many physical systems. For example, thermal vibrations in solids are approximately described by harmonic oscillators. It will be shown that there are evidences that there is universal maximal acceleration. We explore the behavior of the harmonic oscillator under this limitation. For oscillators with small natural frequency, we recover the classical solutions, while for large frequencies, the solutions differ significantly from the classical one. The solutions are a "digitization" of the standard signals of the classical harmonic oscillator. The spectrum of these signals coincides with the energy spectrum of the quantum harmonic oscillator. While for small frequencies, the radiation is a wave type, for large frequencies, it becomes pulses of radiation. Possible experiments to test the new prediction will be proposed and discussed.

Toshifumi Futamase (Tohoku):

A new approximation for non-linear growth of dark matter perturbation and its power spectrum

An accurate theoretical prediction is urgently required to make correct understanding of the nature of Dark Matter, Dark Energy and details of structure formation in the universe from various cosmological observations. I shall present a new approximation scheme which allows us to sum up all orders of perturbation series of Dark Matter perturbation and a new expression for the power spectrum which is accurae up to nonlinear region such as $k \sim 1h^{-1}\mathrm{Mpc}^{-1}$.

Ulrich Geppert (DLR Bremen):

Pulsars and magnetars: Electromagnetic interactions inside and outside neutron stars

Neutron stars are the stellar objects with the largest densities, highest temperatures, shortest rotational periods and strongest magnetic fields in our universe. An overview is given about our understanding of these properties and the physical processes that determine them. Special attention will be devoted to the most fascinating appearance of neutron stars, the magnetars.

Domenico Giulini (ZARM/U Hannover):

Poincaré stresses and classical electron models

After reviewing some history concerning the notion of 'electron spin', I consider classical models of rigidly rotating homogeneously charged spherical shells. I will show that Poincaré stresses enlarge the interval of possible gyromagnetic factors and answer the question of whether classical models with $g = 2$ necessarily contradict Special Relativity (as is often stated).

Jonathan Gratus (Lancaster):

Conservation laws and stress-energy-momentum tensors for systems with background fields

(joint work with Robin Tucker, Lancaster, and Yuri Obukhov, Moscow)

We attempt to delineate the roles played by non-dynamical background structures and Killing symmetries in the construction of stress-energy-momentum tensors generated from a diffeomorphism invariant action density. An intrinsic coordinate independent approach puts into perspective a number of spurious arguments that have historically lead to the main contenders, viz the Belinfante-Rosenfeld stress-energy-momentum tensor derived from a Noether current and the Einstein-Hilbert stress-energy-momentum tensor derived in the context of Einstein's theory of general relativity. Emphasis is placed on the role played by non-dynamical background (phenomenological) structures that discriminate between properties of these tensors particularly in the context of electrodynamics in media. These tensors are used to construct conservation laws in the presence of Killing Lie-symmetric background fields.

Arne Grenzebach (ZARM):

Lensing effects of charged black holes

(joint work with Volker Perlick, ZARM)

I want to talk about two effects of gravitational lensing in the Kerr-Newman-Taub-NUT spacetime: The shadow of black holes and a region with spherical light rays which shrinks to the well known photon sphere in the Reissner-Nordström case. I start with a short general definition of the concept of the shadow of black holes and describe how the shadow of a Kerr-Newman-Taub-NUT black hole can be determined. During this, the crucial point is the existence of (unstable) spherical light rays at a region K which determine the boundary of the shadow. After translation to observable coordinates, the shadow can be viewed via stereographic projection. I demonstrate the influence of an electric charge of the shape of the shadow.

Frank Gronwald (Hamburg):

Engineering electromagnetics: Solving the Maxwell equations in the presence of complex engineering systems

Electrical engineering is based on electromagnetic theory. However, nowadays only a few disciplines of electrical engineering require explicit solutions of electromagnetic boundary value problems. These include antenna theory and electromagnetic compatibility where intentional and unintentional couplings between transmitting and receiving systems are investigated. In this contribution the role of analytical and numerical methods for the determination of relevant coupling paths is explained. While analytical methods can be helpful to obtain a qualitative understanding by means of canonical problems, numerical methods are needed in order to obtain quantitative solutions of actual engineering problems. For the purpose of illustration, the solution of two specific coupling problems are considered: First, a method for the numerical calculation of electromagnetic coupling of electromagnetic fields through carbon fiber composite materials, as used in the aerospace industry, is introduced. Second, it is shown how to solve the problem of a nonlinearly loaded antenna within a cavity by means of an iterative approach.

Norman Guerlebeck (ZARM):

Dipole layers in curved spacetimes

We discuss layers endowed with electric and magnetic dipoles in curved spacetimes. First, we outline the problem of their definition in full general relativity. These difficulties are avoided in a test field approach, which allows us to formulate a geometric definition of dipole layers in arbitrary curved backgrounds. Afterwards, the discontinuities of the electromagnetic test field generated by layers of electric and magnetic monopoles and dipoles are investigated. Our results can be used to interpret the jumps in the electromagnetic field for certain neutron star models. Moreover, an equivalence of magnetic dipoles and electric currents in terms of the field they produce is proven. As an example, we apply the results to "Schwarzschild disk" solutions endowed with electromagnetic monopoles and dipoles. The resulting distributions of charge and dipole densities are corroborated using the membrane paradigm.

Eva Hackmann (ZARM):

Motion of test particles in a regular black hole spacetime

We consider the motion of test particles in the regular black hole space-time given by Ayón-Beato and García in Phys. Rev. Lett. 80:5056 (1998) as solution of the Einstein equation coupled to a nonlinear electrodynamics. The complete set of orbits for neutral and weakly charged test particles is discussed, including for neutral particles the extreme and over-extreme metric. We also derive the analytical solutions for the equation of motion of neutral test particles in a parametric form.

Friedrich Wilhelm Hehl (Cologne):
Maxwell, Heaviside, Hertz: some historical remarks on the emergence of the Maxwell equations
(joint work with Alberto Favaro and Jonathan Lux, Cologne)

Reviewing the five important classical papers of James Clerk Maxwell on electromagnetism, we sketch how Maxwell arrived, starting in 1856, at his field equations first in 1862 and, in a still more satisfactory form, subsequently in 1865. We will display the equations in the original component notation of Maxwell and will provide throughout corresponding translations into the more modern vector calculus. In Maxwell's Treatise on electromagnetism (1873), the field equations are given in a quaternionic form. They look more or less like in vector calculus. However, Maxwell underlines the importance of Faraday's *electrotonic state*, which he describes by the field $\mathbf{A}(x)$, the magnetic vector potential. Maxwell doesn't eliminate $\mathbf{A}(x)$ from his equations. As a consequence, Maxwell's genuine field equations are not what we call nowadays the Maxwell equations. They were rather proposed in their vectorial form by Oliver Heaviside and in their compact component form by Heinrich Hertz. The Maxwell-Hertz equations were taken later by Einstein (1905) for proving the Poincaré covariance of the Maxwell equations.

A. Favaro, F.W. Hehl, J. Lux: *On the metamorphosis of Maxwell's equations during the last 150 years—spotlights on the history of classical electrodynamics—,* in preparation, to be submitted to EPJH (2013)

Yakov Itin (Jerusalem):
Which geometry is predicted by the electromagnetic waves?

Most information about the geometry of the space-time is derived from the observations of the light propagation. This information does not necessarily directly correspond to the proper geometry involved in gravity. I will discuss the effective geometries appearing in the electromagnetic waves propagation phenomena and different algorithms of their derivations. The standard 3-dimensional geometrical optics approximation is substituted by the covariant 4-dimensional geometric optics. In addition, I will discuss the axion electrodynamics where we must go beyond the geometric optics framework.

Yakov Itin (Jerusalem):
Light propagation in anisotropic and skewon media

I will describe a new optic tensors technique for analyzing the light propagation phenomena in a generic media with a linear response. These tensors are the analogs of the Christoffel tensors used in acoustics. For electromagnetic waves, there are two different tensors: the symmetric tensor for the principle part and the skew-symmetric tensor for the skewon. This is instead of a symmetric 3-dimensional acoustic tensor. The optics tensors formalism is shown to be effective in the analysis of the wave propagation. I will consider two different models of linear response media: the bimetric model and the skewon-metric model. Different signatures of metric will be discussed.

Claus Lämmerzahl (ZARM):
G

What is the meaning of the gravitational constant G in modern physics? Why is it so difficult to measure G with a high precision? What is the relevance of G in view of scenarios that aim at unifying all interactions? These are the questions to be addressed in this talk. After reviewing the definition of G and its conceptual meaning, several measuring prescriptions for G will be discussed. Finally, some generalised theories will be considered in which G is no longer a constant, and experimental tests of such theories will be presented.

Christoph Lienau (Oldenburg):
Realizing strong electric fields

Yuri Obukhov (Moscow):
Electromagnetic energy and momentum in complex media

Developing the Lagrangian formalism in the framework of the classical field theory, we revisit the problem of the correct definition of energy-momentum tensors for the electromagnetic field in general linear, non-dispersive and non-dissipative moving media. We discuss how a general definition of the canonical and Belinfante-Rosenfeld tensors provide a way to understand the meaning of different energy-momentum tensors previously considered for the description of the energy and momentum content of the electromagnetic field, among which the Minkowski and the Abraham tensors are the most prominent ones. We develop the relativistic dynamical model for the general linear material medium, with the help of which we demonstrate that in order to avoid confusions in determining a consistent energy-momentum tensor for light in a medium, it is crucial to distinguish whether a system under consideration is open or closed.

Volker Perlick (ZARM):
Self-force in Bopp-Podolsky theory
(joint work with Jonathan Gratus and Robin Tucker, Lancaster)

In the standard Maxwell eletrodynamics, the energy of the electromagnetic field in a sphere around a point charge is infinite. This leads to an infinite self-force and to several pathologies. Two modifications of the Maxwell theory have been suggested to overcome these problems: the non-linear Born-Infeld theory from the 1930s and the higher-order Bopp-Podolsky theory from the 1940s. In both theories the field energy in a sphere around a point charge *at rest* (in an inertial system on Minkowski spacetime) is known to be finite. However, this problem is more difficult for an *accelerated* point charge. Here we demonstrate that in the Bopp-Podolsky theory the field energy and, thus, the self-force is indeed finite, for a point charge on an arbitrary timelike worldline on Minkowski spacetime. The case of uniform acceleration (Rindler motion) is discussed as an example.

Christian Pfeifer (Hamburg):

Finsler spacetime dynamics

Finsler spacetimes are non-metric geometric backgrounds providing a precise notion of causality, observers and field theories. They generalize Lorentzian metric spacetimes in a Finsler geometric setting. After a review of Finsler geometry and its application in physics the Finsler spacetime framework is introduced. As a central point the Einstein-Hilbert action is discussed from this non-metric point of view. It turns out to be the special metric case of a general action defining dynamics for Finsler length measures. By adding suitable matter field theories as source the resulting field equations can be interpreted as gravitational dynamics determining the Finsler length measure of spacetime. Alternatively one can consider special Finsler length measures, for example those built from a vector field and a metric, and interpret the field equation as equation determining these building blocks. This interpretation could lead to a framework which encodes gravity and electrodynamics into the Finsler geometry of spacetime.

Dennis Phillip (ZARM):

Photon accumulation around black holes

(joint work with Volker Perlick, ZARM)

We discuss a gas of collisionless photons propagating on the Schwarzschild spacetime. We calculate the long-time behaviour of the photon distribution function for the case that photons are emitted isotropically from light sources distributed over a sphere of large radius R. In particular, we determine the resulting photon density between the horizon at $r = 2m$ and the light sphere at $r = 3m$. We discuss if, for realistic stellar or supermassive black holes, this density can become so high in the course of time that it would be detrimental to the health of a hypothetical observer near $r = 3m$.

Dirk Puetzfeld (ZARM):

Motion of test bodies in theories with nonminimal coupling

Eugen Radu (Oldenburg):

Higher dimensional black objects with nonstandard horizon topology: including the gauge fields

We discuss the effects induced by the gauge fields on several different classes of black objects with a nonstandard event horizon topology. Starting with the case of nonuniform black strings and caged black holes in Kaluza-Klein theory, we generate electrically charged solutions by using a Harrison-type transformation. We argue that their thermodynamics can be derived from that of the vacuum configurations. Static, nonextremal black hole solutions of the Einstein-Maxwell equations in $d \geq 5$ spacetime dimensions, with an event horizon of $S^2 \times S^{d-4}$ topology, are also considered. These configurations are asymptotically flat, the $U(1)$ field being purely magnetic. They represent generalizations of the dipole black rings, with a spherical distribution of monopole charges but no net charge measured at infinity. The magnetized version of these solutions, which puts them into an external magnetic field, is also considered. Balanced configurations approaching asymptotically a Melvin universe background are found for a critical value of the background magnetic field.

Tzvi Scarr (Jerusalem):

Time dilation and velocity and acceleration transformations in a uniformly accelerated frame

(joint work with Yaakov Friedman, Jerusalem)

We obtain velocity and acceleration transformations from a uniformly accelerated system K' to an inertial frame K. We explain the physical meaning of all terms in these transformations. We introduce the $4D$ *velocity*, an adaptation of Horwitz and Piron's notion of "on-shell." We derive the general formula for the time dilation between accelerated clocks. The time dilation depends on both the position and the velocity of the clocks. We obtain a formula for the angular velocity of a uniformly accelerated object. Every rest point of K' is uniformly accelerated, and its acceleration is a function of the observer's acceleration and its position. We obtain an interpretation of the Lorentz-Abraham-Dirac equation as a transformation of accelerations from K' to K. We will present the possible applications of the results for the description of the electromagnetic field of moving and rotating charges.

Jan Steinhoff (ZARM):

Action principles for extended objects in gravitational and electromagnetic fields

We discuss action principles for extended objects in gravitational and electromagnetic fields. Based on a generic worldline Lagrangian, equations of motion can be derived which agree with the ones obtained by Dixon. While in Dixon's approach the conservation of energy-momentum plays the central role, in the action approach the condition on covariance of the generic Lagrangian is crucial. The equations of motion are discussed for the gravitational case, including contributions from the quadrupole. The quadrupole encodes information about the internal structure of the extended object. In particular, we investigate quadrupole deformation due to spin and tidal interactions. The latter is analogous to polarization in electromagnetism. The relevance of these corrections is studied by deriving a solution for the equations of motion for a simplified configuration in a Kerr background geometry. Further, an inclusion of oscillation modes of the object via the quadrupole is considered. This provides a formalism to analytically describe resonances of orbital motion and oscillation modes in general relativity.