Summary of research interests

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I finished my master studies at University of Wroclaw in 2007, defending the thesis "*Background independent perturbative gravity*". This research, continued later during my PhD studies at Wroclaw Institute for Theoretical Physics, under supervision of prof. Jerzy Kowalski-Glikman, concerned analysis of constrained topological BF theory as a theory of gravity. This formulation has its roots in works of J. Plebanski. My work has been focusing on a model proposed a decade ago by L. Freidel and A. Starodubtsev, which originates from the approach proposed in 70's by MacDowell and Mansouri. In this approach the two independent variables in the Cartan theory (tetrad e^i and $so(3,1)$-connection ω^{ij}) were combined into de Sitter, $so(4,1)$-valued connection A^{IJ} (one can use the anti de Sitter valued connection as well). To get dynamical theory it was necessary to break gauge symmetry from full SO(4,1) theory through the projection of the curvature down to Lorentz subgroup SO(3,1) and building action quadratic in de Sitter curvature with the Hodge star operator. Such formulation leads to the reconstruction of Palatini action and the cosmological constant term with additional Euler invariant. The key idea of Freidel and Starodubtsev was to start with $SO(4,1)$ BF theory containing topological terms and append them by a term quadratic in B fields (having the form known from MacDowell and Mansouri proposal) that breaks the gauge symmetry down to the Lorentz subgroup SO(3,1). The equations of motion of this theory turns out to be the vacuum Einstein equations. By solving the B field equations one finds that the action of this theory (governed only by only three constants α, β, ℓ related to the Newton constant G, cosmological constant Λ, and Immirzi parameter γ) contains not only the standard Palatini action with cosmological constant term, but also the Holst term proportional to the inverse of the Immirzi parameter, as well as a combination of topological invariants (Nieh-Yan, Pontrayagin, and Euler). In this way we obtain the most general form of action, which can be built for first order gravity admitting all necessary symmetries. Additionally, such a deformation of topological field theory has a very intriguing feature. It has a form of first order perturbation around the topological vacuum with a extremely small parameter $\alpha \sim 10^{-120}$, expressed by Λ and G (and modified by parameter γ).

In collaboration with M. Szcząchor and Jerzy Kowalski-Glikman we checked if the proposed BF model (for $OSp(4|1)$ gauge algebra) was appropriate for a supersymmetric extension of the theory. We expanded definition of the connection $\mathbb{A}$ to contain, besides tetrad and connection (now these two belonged together to $SO(3,2)$ group), also the spin 3/2 gravitino field given by Majorana spinor, and we used it for construction of bosonic and fermionic curvature. Subsequently, we reconstructed standard $\mathcal{N}=1$ supergravity. It turned out that in final result there was no contribution from Holst modification. The resulted action was in perfect agreement with action proposed by Neuvenhuizen and Towsend in the late 70's.

Next paper focused on canonical analysis of $SO(4,1)$ constrained BF theory. After proceeding with the Dirac procedure it has been shown that the structure of our model is equivalent to gravity in Holst formulation, with canonical transformation generated by the presence of topological invariants shifting the definitions of the momenta. Finishing the analysis was only possible for manifold without a spacial boundary (contribution from the topological invariants reduced to time derivative of the functional of spacial components of torsion and combination of Chern-Simons forms for self and antiself-dual connection ω). Paper ended with brief discussion of quantization of the theory.

Currently I am working on generalization of the results of this paper to the case of spacetimes with boundaries. These investigations has led me to the problem of conserved Noether currents and charges in the case of the first order gravity. The most important and interesting of them is the charge whose values can be associated with entropy. I hope that my work will let me understand better the role of Immirzi parameter in gravitational physics.

For many years I have been gathering scientific experience. I have attended numerous conferences and workshops abroad and in my country (details in my CV). In the last year of master studies I have participated in the Socrates Program, attending courses at the University van Amsterdam (UvA), Leiden University, Vrije Universiteit and Nikhef. This autumn I have been for six weeks at Nordita Institute in Stockholm on the *Visiting PhD student* program. I gave two conference talks concerning field of my research: "Quantum Gravity^3 in Cracow" (April 2010) and "Quantum Gravity 5th Colloquium" (Paris, Oct 2010), along the institute seminar at Nordita. In April at my home institute I gave talk "Computer applications in modern scientific work" and won 1st prize for *best institute seminar* in academic year 2009/2010. I have always tried to be active in life of my institute. I have been one of the co-organizers of "The Planck Scale 2009" conference held in Wroclaw. Videos from talks were posted online and are available from my homepage. I'm one of co-editors "The Planck Scale 2009, AIP Procceedings, vol. 1196" published from conference materials. I'm skilled in using many tools useful in scientific work (Mathematica, LaTeX, etc) and graphics (Inkscape, Gimp). I was second person in the world who solved five dimensional analog of the Rubic Cube, earlier substantially contributing to its creation. My articles: *"Hamiltonian analysis of $SO(4,1)$ constrained BF gravity"* and *"Supergravity as a constrained BF theory"* were published in Classical and Quantum Gravity (Class. Quantum Grav. 27 185008, [arxiv:1003.2412v1]) and Physical Review D (Phys. Rev. D 81, 045022, [arxiv:0912.1095v1]). I am currently working on completing other articles expected for publication. I expect to defend my PhD thesis at the end of August 2011.

For some decades, parallel to efforts of standard quantization of the gravity, we have dealt with rising number of theoretical results claiming that GR might be not fundamental theory but only effective description of true fundamental degrees of freedom. Then one can see gravity as emergent phenomenon, having its source in averaging microscopic properties of some fundamental system. Crucial role plays here nontrivial connection between thermodynamics and gravity. In early 70's it was stated that laws of dynamics of the black holes have a form analogous to laws of thermodynamics. In his breakthrough work Beckenstein formulated hypothesis that this analogy is in fact an identity, and black hole entropy is proportional to the area of the horizon. Hypothesis was strengthened by Hawking's discovery of the black hole radiation, connected with the fact that black holes have nonzero temperature proportional to the surface gravity. Relation between the entropy and the area, and not the volume, was the starting point of formulating holographic principle. In 1995 T. Jacobson noticed that if one assumes relation between entropy and surface of horizon, the Einstein equations can be obtained as the equation of state. Robert Wald in the late 90's was the first who pointed out that expression for the entropy of black hole in General Relativity (and some of its generalizations) can be interpreted as horizon's Noether charge of conserved Noether current associated with diffeomorphisms. Cases in detail analyzed in the literature concentrated mostly on metric formulation of General Relativity. Model being object of my studies appears to be ideal for checking relation between entropy and diffeomorphic Noether charge for first order formulation. Contribution to the entropy from topological invariants (Pontryagin, Euler, and Nieh-Yan) seems to be essential in the context of gravity treated as a constrained topological field theory. It also allows to expand result for Holst modification, which is quite interesting in the context of entropy obtained in Loop Quantum Gravity framework, and understanding the role and meaning of Immirzi parameter. I would like to explore more other investigations connected with this problem. It concerns the notion of isolated horizons, background subtractions or regularizations by appropriate boundary conditions.

The entropy associated with the structure of gravity is fundamental in bringing us closer in understanding the quantum gravity. I would like to choose this deep, however not fully understood, connection between gravity and thermodynamics as my postdoctoral research path.