Prof. Panagiota Kanti
Email : pkanti@uoi.gr
Tel: 0030-26510-08486
Fax: 0030-26510-08698

Department of Physics
Division of Theor. Physics
University of Ioannina
GR 45110, Ioannina, Greece

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Report on the habilitation thesis of Dr. David Kubiznak

I have accepted with great pleasure and honour the task to act as a referee for the habilitation thesis of Dr. David Kubiznak. Given my scientific interests and although we have never collaborated, I have followed his work for a great number of years and have thus formed a clear, independent opinion of his scientific achievements.

These achievements are very comprehensively presented even to the non-expert reader in his habilitation thesis. The latter begins with an accessible introduction and a hitchhiker's guide to a selection of topics which have been singled out by the author himself as the ones which best describe the spine cord of his scientific endeavours over a period of almost 15 years. A selected bibliography is presented next, and the thesis is completed by a long list of scientific articles published in high-standard international scientific journals, some of them with a notably high impact factor. In the next few paragraphs, I will follow the same outline of the author's hitchhiker's guide as I present my personal assessment of his scientific achievements.

Dr. Kubiznak focuses first on the topic of Black Hole Thermodynamics. In his Introduction, he describes himself as one of the "founders of a new subdiscipline, ..., the black-hole chemistry". To a non-expert this may sound as a non modest description of himself, but the truth is that Dr. Kubiznak does not need to be modest about his contributions in this field. By identifying a dynamical cosmological constant of the Anti de Sitter spacetime with the pressure of the system, as was done by himself and his collaborators, the missing pressure-volume work term from the first law of black-hole thermodynamics was eventually restored and a new, vibrant direction of research was indeed initiated. The notions of geometric and thermodynamical volumes of the black-hole systems were either introduced or re-examined, and different thermodynamical descriptions of a black hole emerged with the black hole mass being interpreted either as the energy of the enthalpy of the system. The first law was then generalised to more complicated forms of black-hole spacetime geometries and unexpected applications soon followed such as the existence of critical points and phase transitions in a variety of black-hole systems. As I will probably not be present in the public defense of the thesis by Dr. Kubiznak, I would like to pose a question regarding this topic:

- The case of thermodynamics of de Sitter spacetimes is not discussed as much in the present thesis since several points remain obscure mainly due to the existence of the second, cosmological horizon. What would the opinion of an expert such as Dr. Kubiznak be regarding the developments of black-hole thermodynamics in this – more interesting from the physical point of view – case and the potential applications?

The next topic selected by Dr. Kubiznak is that of hidden symmetries of rotating black holes. The contributions of Dr. Kubiznak are groundbreaking also in this topic. The employment of the Yano-Killing tensor as a tool to underline the existence of symmetries in the phase space of a gravitational theory was an important development in the field. From a theoretical perspective, it allowed for the determination of the most general background characterised by these symmetries and, at a practical level, led to the separation of Hamilton-Jacobi, Klein-Gordon and Dirac equation as well as the one of vector perturbations. The advent of a generalised Killing-Yano tensor in non vacuum spacetimes extended the application of the formalism to more general theories. A naive question that emerges in the mind of a person who, as myself, has not explicitly worked with the Killing-Yano tensor, is the following:

- Is there a simple expression for the Killing-Yano tensor in the case of a well-known black-hole background such as the four-dimensional Kerr black hole? And, is there a non-vanishing smooth form of it in the limit of zero angular-momentum of the black-hole?

Finally, the topic of modified gravitational theories is discussed. Although the volume of available theories is really vast and sometimes difficult to follow, Dr. Kubiznak has managed to make notable and important contributions. I will mention as indicative examples the generalised quasi-topological gravity and the robust four-dimensional limit of a higher-dimensional Gauss-Bonnet theory. In the former case, the modified gravitational theory that himself and collaborators proposed is a promising theory linking perhaps General Relativity with a more fundamental theory of gravity. In the latter case, he has provided a mathematically and physically consistent way of obtaining the four-dimensional limit of a higher-dimensional gravitational theory which includes th Gauss-Bonnet term thus clarifying the situation after some naive attempts appeared in the literature. Linking this latter class of theories with the topic of black-hole thermodynamics, I would also like to pose the following question:

- In the presence of a scalar degree of freedom in the theory, and thus the association of a black-hole solution with scalar, can the first law of black-hole thermodynamics be modified to include secondary conserved quantities which characterise the solutions such as the scalar charge?

A large number of additional works by Dr. Kubiznak, not discussed above, have also left an important imprint in the literature of gravitational physics. The ones selected above

belong indeed to a subclass of works which create new directions in science and enlarge our horizons in gravity and black-hole physics. His works are always characterised by a concrete mathematical formalism leading eventually to important physical applications. He manages to change the gravitational theory studied each time and to apply his ideas to a variety of gravitational backgrounds with an impressive ease. The contributions of Dr. Kubiznak extend over a period of almost 15 years and have been realised in collaboration with both renowned scientists and younger collaborators. It should also be stressed that his work has received substantial recognition by the scientific community. He has by now become a world expert himself and this is reflected in the present habilitation thesis. I have therefore no reservation to propose that this thesis is accepted by the habilitation committee and in fact I strongly and warmly support this.

Finally, regarding the originality check done with the Turnikin system, although a high percentage of coincidence (%49) was found, I believe that this is due to the fact that the first part of the thesis is inspired by the corresponding scientific articles which are also part of the thesis. Having followed the work of Dr. Kubiznak over the years, I have no doubt that the results presented are the outcome of original research.

Yours Sincerely,

Prof. Panagiota Kanti