FRIEDRICH-ALEXANDER
UNIVERSITÄT
ERLANGEN-NÜRNBERG
NATURWISSENSCHAFTLICHE
FAKULTÄT

Universität Erlangen-Nürnberg • Postfach 3520 • 91023 Erlangen

Department Physik

Institut für Quantengravitation
Lehrstuhl für Theoretische Physik III

Prof. Dr. Hanno Sahlmann

Staudtstr. 7, 91058 Erlangen
Telefon +49 9131 85-28465
Fax +49 9131 85-27704
hanno.sahlmann@gravity.fau.de
www.gravity.physik.fau.de

Ihr Zeichen
Ihre Nachricht vom
Unser Zeichen

Erlangen, September 17, 2016

Subject: Report on the thesis of Jedrzej Swiezewski

Dear colleagues,

I was asked to report on the PhD thesis

Observer's observables — Definition and applications

submitted by Jedrzej Swiezewski. I find that the thesis presents an impressive set of important results and it is definitely up to the standards that one should uphold for a PhD thesis. In fact, based upon the number and importance of the results, and the exemplary presentation, I would suggest the thesis to be nominated as *outstanding*. My detailed report is below.

General covariance is a key property of general relativity. It was an important guiding principle for Einstein on his way to the formulation of the theory, and it lends it an elegance that sets it apart from other physical frameworks. Interestingly, this very principle also leads to problems. Its conceptual ramifications are perplexing enough so that Einstein temporarily became confused, and over time a large (and sometimes contradictory) body of work has been devoted to dealing with its consequences.

Coarsely speaking, the problem is that of identifying the true physical degrees of freedom and separating them from coordinate artefacts. While this could still be regarded as a technical problem in the classical theory, it becomes a deep problem in attempts to find a theory of quantum gravity, and a thorough understanding on the classical level is a prerequisite. One way to eliminate the arbitrariness of coordinate choices is to specify a physical reference system.

Besucheradresse:

Raum Nr. 02.534
Gebäude B2
Staudtstr. 7, 91058 Erlangen

However, the proposals for such systems that are technically manageable introduce potentially unwanted matter degrees of freedom, among other disadvantages. But how else can one construct such a frame of reference with intrinsic meaning? At the core of the thesis, the following answer is given and investigated: An observer will construct a coordinate system by using the angles under which straight lines emanate from the observer's position, and the physical distance along these lines. Such a coordinate system can be constructed for any solution of Einstein's equations, and it can be used to uniquely specify the content of the solution, called the *observer's observables* in the thesis. While this is a conceptually simple and crystal clear solution, without the drawbacks of other proposals, the technical implementation is a different matter. In fact, while the general idea had been formulated by others before, the technical problems seemed unsurmountable. Note that the coordinates depend on the solution in a very complicated way. Here, the thesis delivers a technically brilliant and careful analysis. It manages to elicit the structure of the observer's observables in a form adapted for the quantisation of gravity, both from a gauge fixing perspective and from a Dirac algebra perspective. While this alone is a significant breakthrough, the thesis goes further. It discusses important applications of the results in the context of LQG and of the AdS/CFT duality. The former is a springboard for things to come, while the latter already settles a longstanding dispute about the (non-)locality of Dirac brackets in that context. Both applications show the power of the results derived in the thesis.

More in detail, the content of the thesis is as follows: In the first chapter, a clear and precise introduction to issues related to general covariance are given in the canonical formulation of general relativity. Chapter 2 explains deparametrization, a general technique to deal with the aforementioned problems, and presents an immensely clarifying perspective on a particular implementation (irrotational dust) that had been presented before. Chapter 3 contains the definition of observer's observables. A complicated and careful analysis yields key properties such as the Poisson brackets. In Chapter 4, a gauge fixing procedure (spatial *radial gauge*) using the structure of the observer's observables is presented, both for the case of spherically symmetric GR and for general solutions. In Chapter 5, applications of radial gauge to loop quantum gravity are sketched: connection variables in radial gauge are presented, and reductions to spherical symmetry briefly discussed. In Chapter 6, radial gauge is constructed for the entire spacetime, and key properties are derived. The results are used to answer a long-standing problem posed in connection with AdS/CFT duality; the observables constructed there have complicated non-local Dirac brackets. A summary and discussion of the various results is given in the last section of the thesis.

The thesis delivers an important result: the definition of the observer's observables and the determination of their algebra. The result is very surprising and promising in that the brackets are local, and even canonical for a certain sub-algebra. This guarantees that it will have applications in the quantisation of gravity. In fact, a formulation ready for application in loop quantum gravity is already developed in the thesis. It is also shown that *spacetime* radial gauge is more complicated, in that the brackets become non-local. This has consequences, for example, for applications in AdS/CFT. The results are correct as far as I can see. They have been published in a series of 8 articles that have been well received by the community.

The expositions in thesis are of exemplary clarity. The literature on the subject is often very confusing and opaque, but the thesis is the complete opposite. It is clear that the author has understood the subject deeply. I would recommend the first chapters as excellent exposition of the subject for beginning students. Sometimes calculations are not presented in detail, but the published work then fills in these gaps.

In summary, I find that the thesis presents an impressive set of important results and it is definitely up to the standards that one should uphold for a PhD thesis. In fact, based upon the number and importance of the results, and the exemplary presentation, I would suggest the thesis to be nominated as *outstanding*.

I hope this report is helpful for your purposes. If you have any questions regarding my report, please do not hesitate to contact me.

Yours sincerely,

Prof. Dr. Hanno Sahlmann