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Reviewer's Dissertation Report

Report on

The Doctoral Thesis

String corrections and deformations from double field theory

by **Stanislav Hronek**

The presented thesis discusses the calculation of α'-corrections to the low-energy effective action of closed strings using the formalism of double field theory. Latter allows to take advantage of a new symmetry, called T(arget space)-duality, which is an distinguishing feature of strings. Another established application of double field theory is to extend the notion of abelian T-duality to a broader class of generalized T-dualities which are used as solution generating techniques. A particular example are Yang-Baxter deformations, which are also analyzed in the thesis.

It is organized into two main parts: the first part contains background material on various relevant topics in string theory and double field theory, while the second part presents the original research of the author, and consists of four published articles.

In the first part the author demonstrates a good understanding of the subject. He gives a clear and well-structured introduction to string theory, which is also accessible to non-expert readers. It starts from the Polyakov action, discusses its symmetries and finally described the salient steps of light-cone quantization to obtain the mass spectrum of the closed string. Based on this solid foundation, circle and torus compactifications

are analyzed and the notion of T-duality is introduced. As this duality is a central concept for the thesis, it is discussed in detail and the underlying duality group, O(d,d), is introduced. String theory is a very large field and it is challenging to find the balance between the big picture and all technical details required to cope with research level questions. For example, many nuances of superstring theory are not relevant to the thesis. Still, there are differences between corrections arising for bosonic, the heterotic or type II (super)strings. In section 1.2, the author demonstrates the ability to focus on the relevant parts. He explains the RNS superstring and the GSO projection well at a level which is sufficient for his research and did not get lost in too many technical details. The same holds for the discussion of integrable deformations. Although the general description of α' corrections in section 1.2.3 is correct, there is a slight confusion about the relation between the effective action and β-functions. It is not true that the field equations of the effective action are equivalent to the β-functions. It might look like this at the leading order, but in general there is a non-trivial metric on the coupling space relating the two. This metric is non-degenerate. Therefore it is true that if the field equations are satisfied, the β-functions vanish. However, in the great scheme of things is this a minor mistake.

I like the introduction to double field theory. It is concise and well-written. In section 2.5, it would have been nice when the connection to generalized dualities would have been mentioned, because Yang-Baxter deformation, especially those that apply to integrable deformations, are a special case of them. Also a more detailed description of the generalized Bergschoeff-de Roo identification (gBdRi) would have been beneficial. Details are given in the respective publication, but there are some quite general ideas, like the introduction of auxiliary degrees of freedom which are later removed by a covariant constraint (the identification) which would have helped a non-expert reader to better understand the core results of the thesis.

Four publications, published in JHEP, are a very good result for a PhD student. All of them have been co-authored by the supervisor Prof. Wulff, while the last one additionally has a postdoc, Dr. Zacarias, as co-author. Not being able to judge the exact contribution of the candidate, I still give my general impression of the presented articles. For me, the most influential one is [40] as it points out a conceptional issue of obtaining certain known corrections in the framework of double field theory. This problems have been confirmed by other authors and there is a consensus in the community that implementing these correction is either not possible or at least requires a fundamental change of paradigm. [39] is a natural generalization of previous results, making it well suited to learn the craftmanship of the field while still contributing with valuable results. Finally, I see [41,42] as a very important contribution to the field. Because, they shows that the gBdRi indeed works at order α'^2. There is a lot of technical skill and stamina required to achieve this result. Moreover, (6.35) of [42] suggests a neat generalization of the original proposal for the gBdRi.

To conclude, the presented thesis is well-written. The candidate demonstrates a solid foundation in string theory, dualities, (super)gravity, and geometry. He is able to master

advance computations which do not only need technical skills but also creativity. There are only some minor complaints outlined above. In addition to them, let me raise the following comments/suggestions:

1. Page 9 mentions that Poincaré symmetry is not present for general non-constant metrics. Minkowski space has Poincaré symmetry and we can choose for it coordinates in which the metric is constant. However, we also can choose coordinates in which the metric is non-constant. Hence, there is no need here to emphasis non-constant.

2. Page 35: It should be mentioned that for type IIB the field strength of C_{mnkl} has to be self-dual.

3. Page 36: "In 1986 in work of Metsaev and Tseytlin [17]. MT used 3 point and 4 point string amplitudes to determine the R^3-terms in the gravitational effective actions for the bosonic, heterotic and type II superstring." [17] seems to be the wrong reference here. It obtains two-loop β-functions for the bosonic string. Moreover, the first sentence is not a sentence.

4. Page 37: "...another work by Bergschoeff-de Roo [18] used a different method to calculate the β-functions.". They did not compute β-functions but the effective action.

5. Page 37: "This method allowed to systematically include higher α' corrections while ensuring ...". The method presented by Bergschoeff and de Roo only allowed to compute α'-correction. To go higher, the generalized Bergschoeff-de Roo identification has been introduced.

6. Page 40: "We can view this [the PCM] as one possible example of an integrable string background." The β-functions for the PCM do not vanish. Therefore, it should not be called a string background (which normally implies that the β-function vanish).

7. Page 41: "... integrable deformations involve changing the background (G, B, ϕ) such that the deformed theory remains integrable. In the case of applicatoin of these deformations to backgrounds that are not integrable, they serve as solution generating techniques...". I think this is not correct in general. Let me give just an example: The λ-deformation starts from the integrable WZW model, which is a solution. But all the deformed backgrounds (at least for the bosonic string) aren't solutions. What you say holds for Yang-Baxter deformation. But they are special since they describe generalized dualities which are solution preserving techniques.

8. Page 49: What is written in (2.8) is usually called the weak constraint. It comes from level matching. But what really is imposed here is the strong constraint $\partial_M \cdot \partial^M \cdot = 0$.

9. Page 51, above section 2.3: [38] deals with the construction of covariant expressions for the Riemann tensor. But it does not immediately solve the problem of undetermined components of the connection.
10. The punctuation behind equations have to be checked. Take for example the second equation on page 42. The "Here" after it should be a "here" and there should be no new paragraph. This happens very often.
11. The first part would benefit from more references.

However, these points are minor. Hence, I conclude with:

- In the dissertation thesis, the student has demonstrated his creative abilities in the relevant research area.
- I am recommending the dissertation thesis for defense.

Sincerely Yours,

Falk Hassler
Assistant Professor