Metastring Theory and Generalized Geometries

Laurent Freidel (Perimeter Institute),
Robert G. Leigh (University of Illinois at Urbana-Champaign),
Djordje Minic (Virginia Tech)

03/20/2016–03/27/2016

1 Overview of the Field

Generalized geometry is a very active area of research both in mathematics and in mathematical physics, especially in the context of double field theory and string theory (for review, consult, [1, 2]). From a purely mathematical point of view, generalized geometry is based on the replacement of the tangent bundle TM of a manifold M by $TM \oplus T^*M$, and the Lie bracket by the Courant bracket [1]. On the physics side, the mathematical structure of generalized geometry comes about when one considers the phenomenon of T-duality in string theory, and in particular, the supergravity limit of string theory [2]. The ideas of generalized geometry and double field theory have inspired hundreds of papers in recent years, and many research meetings on these topics have been held in forms of workshops and conferences, including the recent prominent ones at CERN and at the Simons Center for Geometry and Physics.

2 Recent Developments and Open Problems

The field of generalized geometry has been thriving for a number of years. Similarly steady progress has been achieved in using the techniques of generalized geometry in the fields of supergravity and double field theory. However, the real underpinnings of these developments remain largely hidden. In particular, the uniqueness of certain mathematical structures in the context of generalized geometry is not at all apparent. Similarly, the physical viability of the double field theory limit in string theory is not clear. Recently, we have provided a new insight on some of the underlying conceptual issues both from the physics and mathematics perspective [3, 4, 5, 6]. In particular, we have introduced new concepts of metastring theory, modular space-time and Born geometry, which reveal the deeper structures behind T-dualty in string theory, as well as illuminate the appearance of generalized geometry in string theory and point to further generalizations of generalized geometry. Further development of this approach was the central reason for our research-in-teams meeting at BIRS. The outcome of this meeting is summarized in our new paper [7] and an upcoming publication [8]. The results developed during our research conducted at Banff were most recently presented at the meeting on generalized geometry and string theory at the Simons Center for Geometry and Physics, and the same work will be reported at various forthcoming conferences in Amsterdam, Sao Paulo, Prague, Wroclaw, Pretoria and Perimeter Institute.

3 Presentation Highlights

The concept of locality in space-time is one of the cornerstones of modern physics. It is one of the key properties underlying effective field theory, which in turn is widely considered a universal tool to describe fundamental physics and captures the main features of disparate physical systems at low energy scales. Nevertheless, it is becoming increasingly clear that non-locality may play a central role in solving some of the most outstanding puzzles in theoretical physics, such as the vacuum energy problem, the black hole information paradox, as well as the deep understanding of the central non-local features of quantum theory. If this is the case, then the tools of effective field theory become inadequate, and we must develop new ways of thinking. Similarly, the fundamental concepts of differential geometry constitute the basic mathematical language of general relativity, our deepest theory of space and time. However, these tools seem to be just a limiting case of the mathematical language of generalized geometry required to talk about various new phenomena encountered in the areas of supergravity and string theory. In particular, in string theory T-duality is one of the central features, and it also points to the underlying non-local foundations of that field. The concept of non-locality is brought to the forefront in our work on new string constructions involving Born geometry in the context of the so-called metastring theory we have proposed in [5]. This subject ties together disparate ideas in quantum gravity, invoking a notion of relative locality [9] as well as the crucial features of string dualities. The metastring formulation of quantum gravity introduces a new concept of quantum space-time called modular space-time which sheds new light on the foundational issues in quantum theory. Finally the new concept of Born geometry provides a quantum foundation for generalized geometry and opens a new and fruitful area of research in mathematics.

4 Scientific Progress Made

Our meeting in Banff was immensely productive. We worked out the details of the quantum origins of spatial geometry, which has since appeared in [7], and we developed tools for the generalization of the new mathematical structures needed to understand space-time geometry, and their application to metastring theory [8]. This work extends the usual notions of quantization to the most general commutative subgroups of the Heisenberg group, leading to a novel notion of space, which we refer to as modular space. This purely quantum geometry comes automatically equipped with additional metrical structures encountered in the context of metastring theory, and provides the quantum foundations for some open questions in the field of generalized geometry. We have also elucidated how the usual classical notion of space comes out as a singular limit of modular space in the process we call extensification. The week we spent at Banff was crucial in these developments as it gave us a chance to concentrate on these topics for an uninterrupted period of time. In addition to this work, the basic elements of another upcoming publication [8] were developed during the same extremely productive week.

5 Outcome of the Meeting

The outcome of the meeting at BIRS is published in a 34 page paper [7], as well as in the upcoming publication [8]. The results of our meeting at Banff were presented at the meeting on generalized geometry at the Simons center for Geometry and Physics in May of 2016, and are going to be presented at various meetings on string theory, generalized geometry and quantum gravity in Amsterdam, Sao Paulo, Prague, Wroclaw, Pretoria and Perimeter institute, during the summer of 2016.

References

[1] N. Hitchin, *Lectures on generalized geometry*, JCAS Lecture Series in Hong Kong, arXiv:1008.0973 . [math.DG]

[2] B. Zwiebach, *Double Field Theory, T-Duality, and Courant Brackets*, Lect. Notes Phys. **851**, 265 (2012) [arXiv:1109.1782 [hep-th]].

[3] L. Freidel, R. G. Leigh and D. Minic, *Born Reciprocity in String Theory and the Nature of Spacetime*, Phys. Lett. B **730**, 302 (2014) [arXiv:1307.7080 [hep-th]].

[4] L. Freidel, R. G. Leigh and D. Minic, *Quantum Gravity, Dynamical Phase Space and String Theory*, Int. J. Mod. Phys. D **23**, no. 12, 1442006 (2014) [arXiv:1405.3949 [hep-th]].

[5] L. Freidel, R. G. Leigh and D. Minic, *Metastring Theory and Modular Space-time*, JHEP **1506**, 006 (2015) [arXiv:1502.08005 [hep-th]].

[6] L. Freidel, R. G. Leigh and D. Minic, *Modular spacetime*, Int. J. Mod. Phys. D **24**, no. 12, 1544028 (2015).

[7] L. Freidel, R. G. Leigh and D. Minic, *Quantum spaces are Modular*, [arXiv:1606.01829 [hep-th]].

[8] L. Freidel, R. G. Leigh and D. Minic, in preparation.

[9] G. Amelino-Camelia, L. Freidel, J. Kowalski-Glikman and L. Smolin, *The principle of relative locality*, Phys. Rev. D **84**, 084010 (2011) [arXiv:1101.0931 [hep-th]].