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978-1-107-06280-1 - Discrete or Continuous? The Quest for Fundamental Length in Modern Physics

Amit Hagar

Frontmatter

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DISCRETE OR CONTINUOUS?

The Quest for Fundamental Length in Modern Physics

The idea of infinity plays a crucial role in our understanding of the universe, with the infinite spacetime continuum perhaps the best-known example – but is spacetime *really* continuous? Throughout the history of science, many have felt that the continuum model is an unphysical idealization, and that spacetime should be thought of as “quantized” at the smallest of scales.

Combining novel conceptual analysis, a fresh historical perspective, and concrete physical examples, this unique book tells the story of the search for the fundamental unit of length in modern physics, from early classical electrodynamics to current approaches to quantum gravity. Original philosophical theses, with direct implications for theoretical physics research, are presented and defended in an accessible format that avoids complex mathematics. Blending history, philosophy, and theoretical physics, this refreshing outlook on the nature of spacetime sheds light on one of the most thought-provoking topics in modern physics.

AMIT HAGAR is an Associate Professor in the Department of History and Philosophy of Science, Indiana University Bloomington, where he specializes in the foundations of modern physics.

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To my parents

Time is nature’s way of keeping everything from happening at once;
space is what prevents everything from happening to me.

Attributed to John Wheeler

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Preface

How does one end up writing a book on length, you may ask? Truth be told, several years ago I took issue with the quantum information community on matters foundational and practical, such as the role of decoherence in the construction of a large scale and fault tolerant quantum computer [Hag10], and in so doing realized how much physics could benefit from the history and the philosophy of science. Philosophical problems of spacetime physics have always been at the back of my mind, ever since I wrote my MA thesis on the Hole Argument (with the late Itamar Pitowsky) and my PhD thesis on Time's Arrow (under the supervision of Steven Savitt), and I could see that a similar lesson could be learnt in the domain of quantum gravity.

And so began this project on fundamental length. Its seeds were sown in the same place most of my previous ideas for research projects have come from for the last five years or so, namely, in Jeffery Bub's and Robin Schuster's backyard, after a long day of listening to talks by some of the brightest minds in the field of the foundations of physics at the annual "New Directions" workshop, unwinding with a bottle of cold beer and enjoying Jeff's and Robin's warm hospitality on one of DC's crisp spring evenings. Earlier that morning a session had been dedicated to quantum field theories, and the issue of a cutoff (a bound on momentum transfer) kept emerging as crucial to the interpretation of the theory. As I would find out later, and as you will if you read down these pages, this cutoff would become one of the main themes of this book.

That summer, stuck in a remote and secluded Alpine hut, high above Valsugana, not far from Trento, I delved into the history of the continuous versus the discrete, and discovered a whole new world. It was as if millennia-old debates and arguments from the philosophy of mathematics were reincarnated in discussions on the role of fundamental length in field theories, and moreover, as if these discussions from the 1930s were reappearing today in the attempts to construct a quantum theory

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Preface

of gravity. I wrote a concise grant proposal, delineating the benefits of unraveling this *terra incognita*, and went down from the mountain back to the madding crowd.

Many have contributed to the project in the four years that followed. First and foremost, Fred Kronz from the NSF, which generously supported the project from its outset, under grant # SES 0951179 (at this point I should also mention that any opinions, conclusions or recommendations expressed in this book are mine alone, and do not necessarily reflect the views of the NSF). Next, my colleagues from Indiana University, especially Sandy Gliboff (HPS), who helped me with the translation from German of Heisenberg's and Schrödinger's less known papers, as well as Wataghin's papers, The IU Center for Spacetime Symmetries and in particular Alan Kostelcky (physics), who opened a door to the Standard Model Extension and the tests for CPT violations, Gerardo Ortiz (physics) who patiently explained to me how things appear from the condensed matter perspective, and Yuri Bonder (physics).

I am also grateful to C. Alden Mead, now retired from UMN, for revealing, almost 50 years after their publication, the story behind his papers on fundamental length; to Bruno Carazza, now retired from the University of Parma, for sharing his experience as a student of Gleb Wataghin, and for his interest and support of the project; to Roberto Giuntini and his talented group at the University of Cagliari, where the first two chapters of this book were written under the hospitality of the Regione della Sardegna Visiting Professor Program; to Bill Unruh (UBC, physics), whose keen eye for physical fallacies is the sharpest I have ever known; to Tom Banks (Rutgers, physics) who patiently explained to me the intricacies of black hole thermodynamics; to Sabine Hossenfelder, a quantum gravity phenomenologist from Nordita, who runs a popular blog at backreaction.blogspot.com; to Giovanni Amelino-Camelia (La Sapienza, physics); to Olival Freire Jr. and Saulo Carneiro from the Institute of Physics at the Universidade Federal da Bahia, where the final chapter of the book was written, for their hospitality and for discussions; to Osvaldo Pessoa (USP, philosophy) for arranging a meeting with the late Amelia Hamburger, and for getting me access to Wataghin's archives at USP; to Bill Demopoulos (UWO, Canada) and Meir Hemmo (U Haifa, Israel), for being my mentors and friends for so many years, and to the anonymous referees for their comments and their criticism that helped me sharpen my ideas.

Parts of the material in this book – the Einstein–Swann correspondence, the critique on the argument for the consistency of loop quantum gravity with the Lorentz contraction, and the critique on the “disappearance of spacetime” in theories of quantum gravity – were published in slightly different versions in *Studies in the History and the Philosophy of Modern Physics* [Hag08, Hag09, HH13]. The work

presented here is naturally more comprehensive, placing as it does these separate issues in their common context.

Finally, this book could probably have been finished sooner than it actually was without my wife *Adele* and my daughter *Aviv*, but then, it wouldn't have been worth it, would it?