

## The fundamental ontology of the natural world

Scientific report (Nov. 2015 – July 2017)

The research project “The fundamental ontology of the natural world” has been accomplished successfully. The grant of the cogito foundation enabled a fruitful interdisciplinary collaboration between the research group of Michael Esfeld (Université de Lausanne, section de philosophie) and the research group “Interaction between light and matter” lead by Dirk-André Deckert and located at the department of mathematics of LMU Munich. This collaboration resulted in a number of publications in internationally acclaimed journals and will certainly continue in the future. In particular, the project has met its main scientific goal by completing a comprehensive book developing and defending a minimalist ontology of matter underlying modern physics that will hopefully receive wide attention in the philosophical community. The book will be published under the title “A minimalist ontology of the natural world” by Routledge, New York, in the series *Routledge Studies in the Philosophy of Mathematics and Physics* in autumn 2017 (co-authored by Michael Esfeld and Dirk-André Deckert, in collaboration with Dustin Lazarovici, Andrea Oldofredi and Antonio Vassallo). By following the principle of parsimony as the main guide to metaphysics, we develop an ontology of the natural world based on Leibnizian relations between matter points and their change and show how this ontology can ground our most successful physical theories – from Newtonian Mechanics to General Relativity to Quantum Field theory.

The following papers within this project have been accomplished during the funding period:

- “From the universe to subsystems: Why quantum mechanics appears more stochastic than classical mechanics”, co-authored by Andrea Oldofredi, Dustin Lazarovici, Dirk-André Deckert and Michael Esfeld, published in *Fluctuations and Noise Letters* 15 (2016), Special issue Quantum and classical frontiers of noise, pp. 164002: 1-16.
- “What is matter? The fundamental ontology of atomism and structural realism”, co-authored by Michael Esfeld, Dirk-André Deckert and Andrea Oldofredi, forthcoming in Anna Ijjas and Barry Loewer (eds.): *A guide to the philosophy of cosmology*, Oxford University Press.
- “Relationalism about mechanics based on a minimalist ontology of matter”, co-authored by Antonio Vassallo, Dirk-André Deckert and Michael Esfeld, *European Journal for Philosophy of Science* 7 (2017), pp. 299-318.
- “Leibnizian relationalism for general relativistic physics”, co-authored by Antonio Vassallo and Michael Esfeld, *Studies in History and Philosophy of Modern Physics* 55 (2016), pp. 101-107.
- “A persistent particle ontology for QFT in terms of the Dirac sea”, co-authored by Dirk-André Deckert, Michael Esfeld and Andrea Oldofredi, forthcoming in the *British Journal for the Philosophy of Science*, DOI 10.1093/bjps/axx018.
- “A proposal for a minimalist ontology”, by Michael Esfeld, forthcoming in *Synthese*, DOI: 10.1007/s11229-017-1426-8.

- “Collapse or no collapse? What is the best ontology of quantum mechanics in the primitive ontology framework?”, by Michael Esfeld, forthcoming in Shan Gao (ed.): *Collapse of the wave function*. Cambridge: Cambridge University Press
- “Against fields”, by Dustin Lazarovici, forthcoming in *European Journal for the Philosophy of Science*, DOI: 10.1007/s13194-017-0179-z.

Furthermore, the results of this research project figure in the third edition of Michael Esfeld’s introductory book to the philosophy of science in French, *Philosophie des sciences. Une introduction*, Lausanne: Presses polytechniques et universitaires romandes, autumn 2017. These results will also enter into an Italian book entitled *Filosofia della natura*, translated by Tiziano Ferrando and scheduled for publication with Rosenberg & Sellier (Torino) in 2018.

The research grant of the cogito foundation also contributed to the funding of the 5<sup>th</sup> international summer school in Philosophy of Physics titled “Space, Time, and Matter: New Directions in the Philosophy of Physics”, Saig (Black Forest), 17 to 22 July 2017, where the results of our project were presented and discussed in two plenary lectures by Dirk-André Deckert and Michael Esfeld, an evening symposium on the forthcoming book on a minimalist ontology of the natural world and an afternoon work group lead by Dustin Lazarovici. Over and above that, this event attracted some of the leading experts from physics, mathematics and philosophy, working on the foundations of physics, and offered a great opportunity for graduate students and young researchers to present and discuss their work.

During the last 20 months, Dustin Lazarovici did a critical investigation into relativistic interactions and field theories. His research offers a comprehensive discussion of the physical and metaphysical problems arising from a dualistic ontology of particles and fields. It discusses and defends the Wheeler-Feynman theory of classical electrodynamics as a paradigm example of a relativistic direct interaction theory among particles. Finally, it explores the connection between relativistic spacetime structure and the field concept, making a strong and original argument that the concept of fields as mediators of particle interactions reflects a misguided attempt to retrieve Newtonian concepts (in particular the formulation of laws as initial value problems) in a relativistic context.

This work resulted in a paper entitled “Against fields” accepted for publication in the *European Journal for the Philosophy of Science*. The paper, focusing in particular on Maxwell-Lorentz electrodynamics as the *locus classicus* of modern field theory, was presented at this year’s meeting of the British Society for the Philosophy of Science (BSPS) in Edinburgh and will furthermore be presented at the European Congress of Analytic Philosophy (ECAP 9) in Munich in September. It has already received attention at further international conferences. For instance, this paper was positively mentioned at a conference on fundamentality in Oxford in March 2017. I would like to stress that the research on fields is Dustin’s own, autonomous work. It was rather that I learned a lot from Dustin than me instructing Dustin to do certain research work that I supervised.

While the work of Dustin Lazarovici is not *a priori* tied to the relationalist and Humean metaphysics advocated in the book on minimalist ontology, it fits very well into the general theme and scope of the project by showing that the empirical content of relativistic field theories can be recovered in terms of a pure particle ontology and that the admittance of fields as part of the physical ontology leads to physical and metaphysical difficulties without a gain in explanatory power. In particular, it offers a powerful demonstration of the fact that while the existence of electromagnetic fields – at least in the form of light – might seem obvious,

their ontological status is not so obvious: it is something that needs to be investigated and negotiated on the basis of physical and philosophical considerations. This is precisely what we then did in the book.

In sum, part 5, section 2 of the book (“Fields and relativistic laws in classical electrodynamics”) is largely based on Dustin Lazarovici’s paper, spelling out the case against a dualistic ontology of particles and fields and for direct particle interactions in relativistic theories. Dustin also contributed to part 3, section 2 on identity based Bohmian mechanics, describing a formulation of Bohmian quantum mechanics that grounds different particle species in the law of motion rather than in intrinsic properties like mass and charge. Finally, he made substantial contributions to part 3, section 4, which deals with the description of subsystems and the role of probabilities in classical and quantum physics. This is a very important discussion explaining the transition from the fundamental physical description of the universe to the effective description of subsystems that makes a theory useful and relevant for practical applications. It also argues that, contrary to common believe, the status of probabilities or “randomness” in quantum mechanics needs not be different from the one in classical mechanics, although there are compelling reasons why the quantum regime appears more random – and is more unpredictable – than the macroscopic world.

Dustin Lazarovici will continue his research on relativistic interactions, focusing in particular on the tension between relativity and quantum non-locality that is addressed in the last section of the book. In fact, the positive experience within the present research project has convinced Dustin Lazarovici to pursue a career in philosophy of science and to do a second PhD in philosophy supervised by Michael Esfeld. Together with his education in physics and mathematics (PhD in mathematics in 2015), this will put him in a perfect position to do important work at the intersection of physics, mathematics and philosophy.

In sum, we would like to express our gratitude to the cogito foundation for the generous support of an interdisciplinary research project that gave us the freedom to pursue research questions and methods beyond the mainstream research in either physics or philosophy.

28 July 2017

A handwritten signature in black ink that reads "Michael Esfeld". The signature is written in a cursive, flowing style with a long, sweeping tail on the last letter.

Michael Esfeld