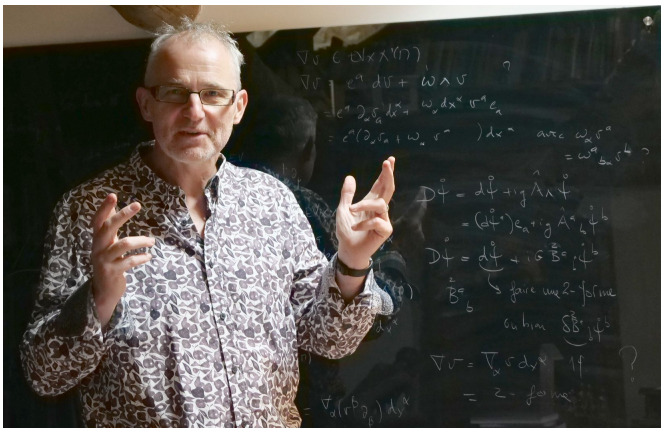
Condensed Matter Physics, 2023, Vol. 26, No. 1, 10101: 1–6
DOI: 10.5488/CMP.26.10101
http://www.icmp.lviv.ua/journal

CONDENSED MATTER PHYSICS

Foreword

Complexity and Collective Behaviour: Solids, Fields, and Data (dedicated to Bertrand Berche on his 60th birthday)



It is our pleasure and honour to dedicate this Festschrift to Bertrand Berche on the occasion of his 60th birthday. Here, colleagues and friends pay tribute to Betrand's long lasting and highly valued work in the fields of statistical and condensed matter physics, complex systems, history of science, philosophy of science as well as interdisciplinary applications.

Bertrand Berche (BB) was born on May 6, 1963 in Metz, France to the family of Anne-Marie and Pierre Berche. His mother was a nurse and his father was a high school teacher of biology and geology. BB was awarded simultaneous master degrees both in physics and in applied physics in 1987 in what was then the Henri Poincaré University of Nancy. BB completed his doctoral dissertation under the supervision of Loïc Turban in 1991 [2][1] and went on to work at Nancy (which later became part of the University of Lorraine), first as an associate professor (PRAG, maître de conférences, 1990–1998) and then, following habilitation in 1997, as full professor from 1998.

Bertrand's teaching career started much earlier and from 1981 to 1990, parallel to his university studies, he was appointed to different school teaching positions, namely elève-instituteur, instituteur, professeur certifié, and agrégé.

With significant depth and breadth of research and teaching experience to hand, BB was able to contribute meaningfully to university governance. From 2008 to 2011 he was the President of one of the sections of the National Council of Universities (CNU, France) — a national body in charge of the qualification, recruitment and careers of university professors. In 2008–2013 he was Director of the Department of Physics and Mechanics at the University of Lorraine and now he is professor at the laboratory for Theoretical Physics and Chemistry there.

BB started his research career in the field of phase transitions and critical phenomena, initially under the guidance of his supervisor, Loïc Turban. It is therefore symbolic that this Festschrift opens with an article written by Loïc. Sadly, it is also Loïc's final publication since he passed away in November 2022. Loïc's legacy endures, however, carried forward not least by BB's renowned breadth of physics knowledge alongside his contributions to new knowledge in multiple fields. The subject of BB's thesis

[1]Here and below we refer to the list of BB's representative publications given at the end of the Foreword.

was conformal invariance, finite-size and surface effects in the critical behaviour of the two-dimensional Ising model [2]. Criticality of two-dimensional classical spin models remained a focus of BB attention throughout his career [1–8]. In later studies, he addressed the influence of structural disorder, inhomogeneities, aperiodicity, and space confinement on phase transitions of various types. He studied the onset of ferromagnetism in two- and three-dimensional magnets [9, 11, 14–16], transitions from isotropic to nematic liquids, as well as topological phase transitions in two-dimensional magnets of continuous symmetry [12, 13, 17, 21, 23]. Over the last decade, BB turned his attention to the problem of critical behaviour above the upper critical dimension, a problem of fundamental importance to the renormalization group formalism generally [31, 31, 39, 43, 51]. For a long time it was believed that hyperscaling and finite-size scaling fail there and it is due to BB and his colleagues that the problem has been resolved by ingenious introduction of a new exponent (koppa) that governs the finite-size scaling of the correlation length. Extension of the concept of dangerous irrelevant variables to the correlation sector was a bold move in explaining the origins of koppa. The new exponent itself was christened by Michael Fisher at a meeting in the Royal Society in London in 2012. Since he was the one who standardised the nomenclature of the other critical exponents in the 1960s, introduced the concept of finite-size scaling in the 1980's, and brought out the danger of irrelevant variables, it was fitting that he be the one to name the new exponent. Hitherto dormant, thanks to BB and colleagues' work in the ensuing decade, the problem of scaling in high dimensions has returned to the front of fundamental considerations of phase transitions and critical phenomena.

Other topics that fall within BB wide range of interests concern collective phenomena of and on complex networks. In this field, he is interested in the question of how the onset of order is influenced by topological properties of many-particle systems. One avenue to pursuing this question involves introducing the powerful framework of partition function zeros (Lee-Yang and Fisher zeros). BB and colleagues used this approach to describe universal features of critical behaviour of spin models on scale-free networks. Another innovation by BB and team is the generalization of the Ising model to make it better fit in descriptions of real-world complex phenomena [37, 48]. Whereas the former studies have been performed by analytic tools of statistical physics, BB and colleagues used a combination of data analysis and numerical simulations to pioneer qualitative descriptions of resilience of complex networks against random and targeted removal of their constituents. Taking public transportation networks of major cities of the world as an example, and using an analogy with percolation phenomena as an archetype, BB and his colleagues have impactfully developed criteria that allow one to forecast the reaction of the networks to random failures and targeted attacks [24, 30].

BB's wide interdisciplinary interests opened him to yet another direction of research, namely the relatively new field of scientometrics [26, 36]. Despite having been discussed and manipulated for decades, the concept of "critical mass" in research was undefined until, in 2010, it was reined in in a theoretical and empirical study of quality of research groups. A linear increase of the quality of research emanating from research groups in the UK and France tapered off once a discipline-dependent size was reached. Capturing this phenomenon using an adjusted mean-field model, this approach also brought statistical physics to the concept of Dunbar's number in Psychology and Anthropology [26]. Continuing in this vein, BB and colleagues were able to show that modern-day scientometrics fall far short of being able to reflect peer review in "measurement" of academic research quality — especially in non-STEM subject areas. This work went a considerable way to halting the tide of metrics sweeping from the UK across the academic world [36].

More recently, BB made important contributions to the theory of spin transport in semiconductors, analyzing compounds with strong spin-orbital coupling and applying gauge symmetry to characterize topological aspects of such systems. Together with his colleagues he analyzed a whole series of phenomena which, although occurring in different materials, have in common the fact that the curvature influences the dynamics of quantum particles. This common underlying feature made it possible to describe the problem of persistent charge and spin currents on a Corbino disk built from a graphene sheet [34] — a task important for manipulating the electronic properties of two-dimensional materials, electronic ballistic transport in deformed nanotubes [38] and to study the electron spin transport on a helix [35] as well as offering analytical models to study electron transfer in DNA [45, 49].

As part of the traditional responsibility of the research community, BB has risen to the challenge of making scientific knowledge and developments available to students and the broader public. To this end,

he regularly publishes more pedagogic version of his scientific achievements, with lay explanations of the models and methods he used [18, 27, 41, 46]. A perfect example of this is the publication [46]. There he and his coauthors also advocate, by citing Lawrence Bragg, "the important thing about science is not so much to obtain new facts as to discover new ways of thinking about them".

Another important part of BB's work concerns the history and philosophy of science [19, 25, 28, 42, 50]. Even in his PhD thesis [2], he began with an extended historic introduction to critical phenomena [an "avant-propos"]. He revisited historical matters from time to time throughout his career. This included publications to mark the anniversary of the death of Cagniard de la Tour [25] as well as the history of Ernst Ising and the Ising model [42]. Quite recently he again contributed [50] to the *Ising lectures* with a topic which, while at first sight might seem to be far away from Ising, but which in fact related general relativity to solid state physics by considering torsion in spacetime. In several papers it is shown how this transdisciplinary relation is useful for the understanding of the behavior of quasiparticles in systems with topological defects [33, 50]. For that purpose he used the analogy between the classical Maxwell theory and the Kalb-Ramond theory [49]. As a result, it turned out that the Kalb-Ramond field is a candidate to describe the torsion of spacetime. Another example concerns the tunneling of electrons in metamaterial by considering the tunneling between two different spacetimes [40] or the propagation of light in liquid crystal-based metamaterials in analogy to tachyons in the compactified Milne universe geometry [44]

Touching on philosophy, nowadays there is a discussion about the way physicists and especially theoretical physicists approach the puzzles that the nature poses to us. After a time where mathematics was introduced to physics, and physics to fields like chemistry, many others fields — even those as far away as sociology and humanities — became impacted by mathematics. So we again, as theorist, ask if we can express everything using mathematics as language. In his overview of the debate of hidden variables in quantum mechanics [19] BB confessed: "This is a personal comment more than a question. I believe that physicists' common conception of a physical theory is very constraining. Couldn't we imagine as admissible a theory which would not be able at all to answer (I mean even not in probabilistic terms) some questions which are a priori from its domain of applicability? Something a bit like Gödel's theorem and propositions which are neither true nor false. Why do we ask so much to our theories? Isn't it due to our custom that physical theories have been so powerful in the past, with the 'The Unreasonable Effectiveness of Mathematics in the Natural Sciences' of Eugene Wigner". Thus, BB has never been afraid to tackle some of the deepest questions — not just within physics but beyond to other disciplines and to philosophy.

BB's contribution to the scientific community has been, and continues to be, greatly valued by statistical physicists and beyond. Early in his scientific career, he participated at the 18th conference of the *Middle European Cooperation in Statistical Physics* (MECO) organized in 1991 in Duisburg (West-Germany at that time). In the year 2000 he organized MECO 25 in France and became member of the select Advisory Board. As can be seen from the analysis by Olesya Mryglod presented in this Festschrift, he contributed very significantly to the continuation and extension of this yearly conference. BB is a member of the editorial board of the Condensed Matter Physics journal. BB is one of the founders and co-directors of the world-renowned $\mathbb{L}^4$ Collaboration and Doctoral College for the Statistical Physics of Complex Systems. This joins Universities of Leipzig, Lorraine and Coventry with the Institute for Condensed Matter Physics (ICMP) in Lviv and aims at teaching young generations of physicists and enabling their co-tutelle PhD studies. He is a co-organizer of the *Atelier Nancy*, a traditional meeting in Statistical Physics and Low Dimensional Systems and of the annual interdisciplinary meeting of natural scientists, philosophers, historians of science and mathematicians - a *Seminar Cathie Dufour* - named after a late Colleague and friend from the university of Nancy [33]. Numerous bi- and multilateral international research projects where he was a principal partner, joined him with colleagues from Brazil, England, Equador, Germany, Hungary, Italy, Mexico, Ukraine, Venezuela and many other countries. His lecture courses prepared generations of young physicists not only in France and elsewhere in Europe, but also in other countries such as Venezuela, Mauritania and Cameroon. As was written in the preface to the publication of the illustrious lectures at the *Mochima theoretical physics spring school*, that he organized in Venezuela in 2005 [20]: "Our objective was essentially pedagogical, as we were interested in motivating the students to learn and to go on studying physics, through a close contact with known scientists in a pleasant place appropriate for scientific discussions." BB has followed this maxim until now.

BB's laudible community contributions reach far beyond the academic and should not go unmentioned. As is the indelible responsibility of independent thinkers, he has never wavered in speaking out at injustice in the community at large — holding authority to account to maintain the principles of *liberté, égalité, fraternité* which he so admirably adheres to and inspires others to follow. We do not enumerate the many instances he has stood up for the downtrodden, oppressed and victims of injustice, both because they are too numerous and because many are private. Suffice to mention his activities defending human rights in general, the rights of university employees, of students and of immigrants in France and other countries. A recent example is his outspoken support for Ukraine against Russian aggression.

In 2016 the degree of Doctor honoris causa of the ICMP NAS of Ukraine was conferred on Bertrand Berche with the formulation "for the studies which provided explanation of changes in the critical behaviour of complex systems under the influence of structural disorder, inhomogeneities, aperiodicity, and space confinement as well as for the engagement in preparation of young scientists and for his personal initiative in different forms of collaboration between France and Ukraine". Openness and engagement for cooperation, the seek for new knowledge, and necessity to share it with the surrounding world for its benefit are familiar to all of us who know Bertrand personally. We ourselves have many times benefited from the kind way he contributes to such common work and we look forward to much more of this. On behalf of the authors of this Festschrift, of numerous colleagues and friends we sincerely wish Bertrand good health, good spirits and many more years of fruitful activities.

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List of representative publications of Bertrand Berche:

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