Il Colle di Galileo

Topological properties of gauge theories and their applications to high-energy and condensed-matter physics

Arcetri, August 23 - October 01, 2021
Organizers:
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Abstract. Many remarkable properties of gauge theories rely on the topology of field configurations and/or ambient spacetime and are connected with quantum anomalies and nonperturbative excitations. These often exact properties have many implications on the physics of fundamental interactions, condensed matter systems and statistical mechanics models. They also account for a large part of the investigations in string theory and, combined with supersymmetry, have led to exact solutions of low-energy theories and the discovery of duality relations between supersymmetric gauge theories. The goal of this GGI activity has been that of bringing together theoreticians from different backgrounds, in condensed matter, high energy and mathematical physics, and encouraging discussion and collaboration.

Keywords. Quantum field theory anomalies, topological excitations, topological states of matter, field theory dualities.

Context

A renewed interested in topological aspects has emerged from condensed matter physics in recent years, through the study of topological phases of quantum matter. Their low-energy properties are not determined by the behaviour of the local order parameter but follow by the presence of global effects and massless boundary excitations. The bulk features can be described by topological gauge theories and the boundary excitations by relativistic effective theories. In the simplest case, boundary excitations are massless fermions and their quantum anomalies provide a robust characterization. Topological invariant quantities, associated to the anomalies and taking integer values, classify the possible phases. In the case

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of interacting states and boundary excitations, the classification is not yet understood and this has led to intense investigations of topological theories and global anomalies. These studies have come in relation to independent analyses of the low-energy phases of supersymmetric theories, in three spacetime dimensions in particular, and their non-perturbative duality relations. Other researches into the properties of extended objects, like Wilson loops and defects, carried out over the last five to six years, have also found an interplay. These interdisciplinary research connections have led to substantial progress which continues today.

Topics

Anomalies of quantum field theories
Generalized symmetries
Topological aspects of quantum states in condensed matter
(Supersymmetric) dualities in (2+1)-dimensions
Time-reversal symmetry and 4d theta-terms

Scientific activity

The workshop was run in dual mode, in presence and online. Thanks to the GGI audio-video facilities, all seminars and lectures were broadcast on Zoom. A discussion channel was also set up on the Slack platform.

The scientific activity was broadly divided in three two-week sections.

Weeks 1-2: topological phases of matter; weeks 3-4: symmetries and anomalies; weeks 5-6: dualities, supersymmetry, bosonization.

Each week, a two-hour lecture was delivered by key participants, either in-person or online, to introduce the themes. These lectures were also meant to present the subjects to a broader audience that usually participates in the conference associated with the workshop, which could not be organized due to COVID.

The schedule involved an average of two seminars a day plus informal discussions and lectures, which were planned rather spontaneously following debates among participants. Speakers and topics of the informal sessions included: A. Cappelli and C. Mudry (classification of topological phases of matter) J. Viti (entanglement in quantum field theory), P. Nair and P. Putrov (global anomalies and cobordism), P. Wiegmann, P. Nair and A. Abanov (hydrodynamic approaches), M. Bertolini and D. Delmastro (phases of supersymmetric gauge theories), D. Brennan (higher-form symmetries). These informal off-the-record discussions were particularly appreciated by participants.

Attendance and funding

This workshop was the first in-person GGI activity after the break of over a year due to COVID. It began on August 23, 2021 and lasted six weeks. There were 50 in-person participants in total, most of them came for two weeks, but there also were longer stays. The average participation was 20 people per week. There were about 25 online participants, attending and presenting lectures and seminars. These should be considered as very successful figures given the circumstances: many planned participations were cancelled due to travel restrictions. We actually received more than 100 applications, but many did not come.

Four distinguished scientists attended the workshops for an extended period, supported by the Simons Foundation: Alexander Abanov (Stony Brook Univ, USA), Riccardo Argurio (ULB, Bruxelles), Christopher Mudry (PSI, Villigen, Switzerland) and Parameswaran Nair (City College, New York,USA). Among the organizers, Andrea Cappelli (INFN, Florence) stayed for six weeks, Francesco Benini (Sissa, Trieste) for four weeks and Paul Wiegmann (Chicago University, USA) for two weeks. Another participant, Shinsei Ryu (Princeton University, USA) could not come but attended all the online activities throughout the six weeks.

From the point of view of logistics, everything went smoothly thanks to the excellent support by the GGI staff. The COVID sanitary precautions were very carefully implemented. A social dinner was held every week at a nearby open-air restaurant, which helped welcome the new arrivals and socialize in an informal setting.

Final remarks

Altogether, we believe the workshop was very successful at scientific level. The participants really enjoyed meeting and talking to each other in person again after many difficult months. Many were young researchers and postdocs who had the opportunity to present their work and learn new topics from various communities. Video recordings, slides and other complementary material stored in the Slack channel (notes and papers of informal discussions) provide a valuable source of information on this field of current research.