Women at the Intersection of Mathematics and High Energy Physics

MITP Workshop organized by

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This workshop has brought together mathematicians and theoretical physicists working at the forefront of research in areas of mathematical physics which share analytic, algebraic geometric and number theoretic methods as underlying common features. The workshop focussed on applications of these methods in the context of quantum field theory, quantum gravity and string theory. The program was centred broadly around the concepts of (i) Locality and observables, (ii) Symmetry and duality, (iii) String compactifications, (iv) Numbers and singularities. The program consisted of 90 minute introductory talks on Monday to Thursday mornings and 45 minute research talks in the afternoons and on Friday morning. The schedule thus was sufficiently light to allow ample time for free discussions in the breaks and afternoons. The character of the workshop was very interdisciplinary. This is not only reflected by the diverse list of external participants, but also by the fact that local mathematicians and theoretical physicists attended the event.

In addition to the scientific program, a public outreach event was organized on the International Women's Day, Wednesday 8 March 2017, where Anda Degeratu (Freiburg and Stuttgart) gave a public evening lecture titled "Wie Gravitationswellen unser Bild vom Universum erweitern", at the "Akademie der Wissenschaften und der Literatur Mainz".

Beyond its ambitious scientific goals, the concept of the workshop aimed to promote women, who are represented by a lamentably small fraction of researchers in the field, to the very date. To achieve this goal, world-leading women in their respective fields where chosen as speakers. The percentage of men who had applied to participate in the workshop was low. Following the sole selection criterion that participants should actively work within the broad scientific scope of the workshop, 9.4% of the participants were male (3 men, 29 women participants).

Anne Taormina (Durham) opened the MITP workshop with a pedagogical review on **string theory** as unified theory of all fundamental interactions and the challenges posed on the **compactification** of six extra space-like dimensions to match four-dimensional gauge

and gravity theories. Xenia de la Ossa (Oxford) continued to review the mathematics of particular compactifications of heterotic string theories and discussed open issues in the description of vector bundles and moduli spaces. The shorter research talks by Mariana Graña (Saclay) and Michela Petrini (LPTHE Paris) addressed pressing open questions that arise when generic closed string background fluxes are included. Thus, the six compact dimensions do not constitute a Calabi-Yau variety but have to be described by the mathematical framework of Generalized Geometry, or for sufficiently simple backgrounds by means of Double Field Theory. The research talk by Magdalena Larfors (Uppsala) further discussed the mathematical issues that arise when the compact space is enhanced by one dimension to form a G_2 manifold. This can be used to describe the flow between different geometries with $SU(3)$ structure. The application of geometric descriptions of Calabi-Yau varieties of complex dimension four was discussed in the research talks by Antonella Grassi (U. Penn) and Mirjam Cvetič (U. Penn) in the context of the so-called F-theory, which interpolates between Type IIB string theory at strong string coupling and the heterotic $E_8 \times E_8$ string theory. While Antonella Grassi focussed on ongoing research in algebraic geometry and on topology features, in particular the structure of singularities which determine the four-dimensional gauge theory, Mirjam Cvetič focussed on the relation of the geometry to discrete **gauge symmetries**.

The review talk by Johanna Knapp (TU Vienna) focussed on newly emerging complementary techniques to describe **string compactifications** by means of Gauged Linear Sigma Models on the string worldsheet, which allow to compute quantum corrections to the four-dimensional effective field theory. The discussion of supersymmetric field theories was picked up by Marialuisa Frau (Turin), who presented new techniques of resummation for all the instanton contributions that are not treatable with other techniques in four dimensions.

Valentina Forini (HU Berlin) extended the discussion of sigma model techniques and **dualities** to extract finite coupling information, which is of great interest in the context of the AdS/CFT correspondence, and she confronted analytical extrapolations with numerical results from lattice field theory. Also related to the study of dualities was Mara Ungureanu's (HU Berlin) research talk, in which she described a classical enumerative problem, the Jonquière count of certain prescribed hyperplane tangency conditions to a smooth curve embedded in projective space, and related it to certain ergodic dynamical systems, thereby making the connection between enumerative geometry and cohomological field theory.

A series of talks dealt with **singularities** in quantum field theory. A way to circumvent infrared singularities is to work on a discrete spacetime where the path integral becomes finite-dimensional. In her introductory talk, Catherine Meusburger (Erlangen-Nürnberg) explained how the concept of a lattice gauge theory with values in a group can be generalised to a gauge theory with values in a Hopf algebra on a graph embedded into a surface. She set up a relation between Kitaevs lattice model – a special case of the older and more general combinatorial models – for a finite-dimensional semisimple Hopf algebra and the

combinatorial quantisation of Chern-Simons theory for its Drinfeld double. Singularities can serve computations, as exemplified in an introductory talk by Ruth Britto (Dublin & CEA Saclay) on scattering amplitudes and singularities. It presented the physical context in which amplitude calculations are required, with a focus on singularities and discontinuities as key tools for exploration and computation.

Singularities are inherent to Feynman integrals, one of the most important tools of perturbation theory for high precision calculations in particle physics. Feynman graphs is where **singularities** and **numbers** meet, since intriguing numbers arise from Feynman graphs. Luise Adams (JGU Mainz) addressed the question as to what type of functions appears in the Laurent expansion of regularised Feynman integrals and showed that the constant term of one-loop integrals involves the logarithm and the dilogarithm. Similarly, many multi-loop integrals can be expressed in terms of generalisations of the logarithm and the dilogarithm, the so-called multiple polylogarithms. But not all fall into this class, and Luise Adams showed how the multiple polylogarithms can be generalised to express the constant term in the Laurent expansion of some Feynman integrals such as the sunrise integral. Number patterns in Feynman graphs was the topic of Karen Yeats' (Simon Fraser University, Burnaby) talk which provided a pedestrian introduction to periods of Feynman graphs, showing their relevance for both mathematics and physics.

Motives and graphs was the subject of Susama Agarwala's (U. S. Naval Academy, Annapolis) talk, in which she gave a different graphical representation (unrelated to Feynman diagrams) for the numbers that arise as amplitude calculations in quantum field theories (QFTs), i.e. mixed Tate motives.

Daniela Cadamuro (Göttingen) in her talk about **locality of observables** presented a pedagogical introduction into mathematically rigorous treatments of QFT. She started with Wightman axioms and then moved on to Haag-Kastler axioms and to the presentation of new developments in algebraic quantum field theory. Kristina Giesel (Erlangen-Nürnberg) gave an overview talk on loop quantum gravity and pointed out conceptual difficulties with the notion of observables in quantum gravity.

The workshop was a great success, as can be seen from the impressive scientific quality of the talks, covering a broad choice of topics. The talks were flanked by lively discussions, which continued into the coffee and lunch breaks, where scientific ideas were exchanged and further developed. The speakers and participants represented a cross section of scientists including experienced and established researchers, postdoctoral fellows and advanced graduate students. This created a friendly and stimulating atmosphere, which was highly appreciated by the participants, as was the diversity of topics.