

# Statistics, Quantum Information, and Gravity

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Unification of general relativity and quantum mechanics has been one of the holy grails of modern physics. After the discovery of the Ryu-Takayanagi formula for the entanglement entropy 10 years ago, it has become increasingly clear that information theory provides powerful tools to study quantum gravity and quantum field theory. In turn, the study of quantum gravity has provided a new set of problems that information theorists can study and stimulated its progress.

In the past, the Kavli IPMU has successfully hosted Focus Weeks at the interface of high energy physics and condensed matter physics, and they have led to new collaborations between theorists at the Kavli IPMU and condensed matter theorists at other institutes. The purpose of this one-day conference is to explore another interface area, between high energy physics and information theory.

We invited a broad range of scientists as speakers: Masanao Ozawa (who studies quantum information theory and foundations of quantum mechanics), Hal Tasaki (who studies fundamental questions in statistical mechanics), Takahiro Sagawa (who studies non-equilibrium statistical mechanics, quantum measurement, control and information theory), Yasuyuki Kawahigashi (who studies operator algebras, which are

important for quantum field theory), and Simmeon Hellerman (who is at the Kavli IPMU and studies string theory, which is the leading candidate for the unification of general relativity and quantum mechanics).

Ozawa is well-known for his discovery of “Ozawa inequality” in quantum measurement theory. The conference opened with Ozawa’s talk, in which he discussed measurement theory in quantum field theory. He was followed by Kawahigashi, who discussed operator algebraic approach to conformal field theory, which is an important class of quantum field theories, relevant to many aspects of string theory and AdS/CFT correspondence. In the afternoon,

Tasaki discussed thermalization of statistical systems and Sagawa used information theoretic methods to discuss fundamental questions in statistical mechanics. The conference ended with a talk by Hellerman, who pointed out an issue with defining quantum entanglement in quantum field theories with non-vanishing gravitational anomalies.

The conference offered an excellent opportunity for scientists with such a broad range of backgrounds to interact with each other. We hope to foster such interactions further and encourage collaborations between high energy physics and information theory.



# Workshop on Categorical and Analytic Invariants in Algebraic Geometry IV

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The year 2016 was final for the bilateral Japanese-Russian project “Categorical and Analytic Invariants in Algebraic Geometry.” It was financially supported jointly by JSPS and Russian Foundation for Basic Research (RFBR). The project is governed by Kyoji Saito and Alexey Bondal.

In 2016, the series of events started in 2015 was continued. A conference “Categorical and Analytic Invariants in Algebraic Geometry III” under the auspice of this project was organized by the Kavli IPMU, Steklov Institute, Higher School of Economics in Moscow (where this conference was held) and the Institute of Fundamental Science on September 12–16. Members of the Kavli IPMU participated, as well as mathematicians from the Graduate School of Mathematical Sciences of Tokyo University, Osaka University, Tokyo Metropolitan University, Steklov Institute in Moscow, Higher School of Economics in Moscow and from other institutions in Britain and Poland.

Another workshop “Categorical and Analytic Invariants in Algebraic Geometry IV” took place at the Kavli IPMU in the week of 14–18 November 2016. Further exchange of ideas and cooperation between Japanese and Russian participants of the project as well as with other Russian and Japanese scientists took place.

A particular attention was given to birational transformations and their mirror symmetric partners. Constructions of derived equivalences of algebraic varieties given by both birational and nonbirational varieties

were discussed. Noncommutative mirror partners of ordinary algebraic varieties were scrutinized. The foundational base of the theory via properties of DG-enhanced categories, introduced by A. Bondal and M. Kapranov almost 30 years ago, was carefully studied.

The work of analytical invariants constructed by means of mirror symmetry was presented in several talks from the Japanese side. As in the events of the previous year, many talks of the workshop were devoted to the study of one of the sides of the mirror and/or to comparison of the two.

Mikhail Kapranov outlined a new perspective in his talk on higher Kac-Moody algebras and derived moduli spaces of  $G$ -bundles. He developed a generalization for higher dimensional varieties of one of the fundamental features of the Conformal Field Theory on Riemann surfaces, that is the action of the current (Kac-Moody) algebras on the moduli space of rigidified  $G$ -bundles.

A young Japanese mathematician T. Kuwagaki presented his powerful result on coherent-constructible correspondence. The first observation and results of A. Bondal on equivalence of derived categories of coherent sheaves on toric varieties with the derived categories of constructible sheaves on the real torus

subordinated to a suitable stratification was developed by a range of authors into a general conjecture of such equivalence for toric stacks. The conjecture can be interpreted in terms of mirror symmetry by identifying the constructible side with the relevant Fukaya category. T. Kuwagaki reported on his proof of the conjecture in full generality.

The cooperation with physicists was particularly fruitful. Kentaro Hori presented mathematical conjectures about derived equivalences of some Calabi-Yau varieties based on consideration of a two parameter gauged linear sigma model that has six phases. It can be regarded as a two parameter extension of Hosono-Takagi model. Sh. Hosono in his turn described a series of examples of mirror symmetric partners for Calabi-Yau varieties that have infinite birational automorphisms and identify these automorphisms with monodromy transformations in their mirror families.

A young Russian mathematician Andrei Yonov developed the physics proposal of A. Belavin that the Witten’s descent deformation of the chiral ring should correspond to the certain K. Saito’s primitive forms for the Gepner singularity. Yonov constructed by purely mathematical tools primitive forms for Gepner singularities.



# Resurgence at Kavli IPMU

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The “Resurgence at Kavli IPMU” was held from December 12 to 16, and focused on surveying recent developments in resurgence theory and related topics. Resurgence theory is a framework to systematically construct solutions to non-linear problems arising in physics and mathematics. For example, one may want to construct solutions to non-linear differential equations, or to write expressions for observables in a quantum field theory (QFT) as a function of its coupling constants. The starting point for the analysis of such problems is of course perturbation theory around a linearized limit. But perturbation theory alone is usually not enough, because it produces divergent asymptotic series, and the result is not valid non-perturbatively. Resurgence theory allows one to develop exact solutions by systematically putting together perturbative expansions around different linearized limits. For example, in QFT, this involves understanding how perturbative fluctuations around various instanton-like sectors fit together to produce an unambiguous result valid for any value of the coupling constants.

The workshop was highly international, with participants from Europe, North America, South America, and Asia. The talks highlighted exciting developments along several directions. Many talks, for example by Y. Tanizaki,

T. Schafer, E. Poppitz, P. Putrov, G. Basar, and T. Misumi, discussed the relation between resurgence theory, which gives an algebraic perspective on semiclassical expansions, and Lefschetz thimbles, which give a geometric perspective on the same topic. A. Cherman and T. Sulejmanpasic gave overviews of techniques necessary to produce smooth weakly-coupled limits for asymptotically-free QFTs, which is a necessary step to apply resurgence theory techniques. O. Costin and G. Dunne announced intriguing results on practical new methods for summation of semiclassical expansions and relations between perturbative and non-perturbative effects. R. Schiappa and M. Yamazaki explained recent developments in applications of resurgence theory to string theory and

supersymmetric gauge theory, while T. Aoki, Y. Takei, and A. Getmanenko presented advances in the study of the WKB expansion and related topics in resurgence and Stokes phenomena.

The format of the workshop was focused on leaving as much time for informal discussion as possible, with most days having two talks in the morning and two in the evening, and plenty of tea and cookies placed near blackboards to trigger interactions. Kavli IPMU’s wonderful staff and facilities provided an excellent and stimulating environment, and the workshop was very successful, with many participants remarking that they developed new research ideas from the talks and interactions with other researchers.

