Abstracts of Invited Talks

Louis Pierre Arguin  
City University of New York
“The maxima of the Riemann zeta function in a short interval of the critical line”
A conjecture of Fyodorov, Hiary & Keating states that the maxima of the modulus of the Riemann zeta function on a short interval of the critical line behave similarly to the maxima of a disordered system with logarithmic correlations. In this talk, we will discuss a proof of this conjecture to leading order, unconditionally on the Riemann Hypothesis. We will highlight the connections between the number theory problem and the relevant spin glasses (REM and disordered polymers on a tree), which exhibit a 1-RSB freezing transition.
This is joint work with D. Belius (Zurich), P. Bourgade (NYU), M. Radizwill (McGill), and K. Soundararajan (Stanford).

Roland Bauerschmidt  
University of Cambridge
“Spin systems and interacting random walks”
I will briefly review the role of random walks in the study of spin systems. I will then present a new relation that shows directly that the Goldstone mode of hyperbolic sigma models (in any dimension) is described by an interacting random walk (the vertex reinforced jump process).

Gyan Bhanot  
Rutgers University
“What are physicists doing working at the Cancer Institute?”

Marek Biskup  
UCLA
“Random walks on dynamical percolation and other degenerate environments”
I will consider random walks among dynamical random conductances (on cubic lattices) where the conductance of an edge gives the instantaneous rate by which this edge is picked by a walker that happens to be at one of its endpoints at that time. The conductances are assumed bounded (say by one) but otherwise just jointly ergodic with respect to space-time shifts. Importantly, conductances are allowed to vanish for non-trivial intervals of time so the walk may be stuck at a point for arbitrary long periods of time. I will sketch the proof of convergence of this walk to a non-degenerate Brownian motion under diffusive scaling of space and time based only on the assumption that the time to accumulate unit conductance on a given edge has sufficiently high moments. This proves Brownian scaling for random walks in a class of dynamical percolation models, as well as those in random environments arising in the Helffer-Sjostrand representation of gradient models with non-strictly convex interactions. Joint work with Pierre-Francois Rodriguez.

Christian Borgs  
Microsoft
“From Graph Limits to Non-Parametric Graph Models and Estimation”
Graphons were invented to model the limit of large, dense graphs. While this led to interesting applications in combinatorics, most applications require limits of sparse graphs. In this talk, I will review recent progress on graph limits for sparse graphs, and then discuss applications to non-parametric modelling and estimation of sparse graphs. This is joint work with Jennifer Chayes, Henry Cohn, and many others.
Jasna Brujic
NYU
“Self-assembly and Folding of Colloidal Emulsion Polymers”
An important goal of self-assembly is to achieve a preprogrammed structure, which can respond to external queues to perform a specific function. Here we show that DNA-mediated droplet interactions can be finely tuned in a way that ensures the self-assembly of colloidal emulsion polymers with a broad distribution of chain lengths. The obtained distributions are consistent with a random branching model for droplets with pre-prescribed valencies, indicating that the self-assembly process is well mixed and goes to completion. We show that these polymers are freely-jointed chains and that their size R scales with the number of monomers N as R~bN^a, where b is the droplet diameter (or Kuhn length) and a=3/4, in agreement with the Flory theory for a dilute polymer in a good solvent in 2D. In addition, we find that the diffusion constant of the center of mass of the polymer scales as D~N^1/2, suggesting that the hydrodynamic drag force on the polymer due to the solvent is important. Finally, we introduce and trigger secondary DNA interactions along the polymer backbone to fold it into several simple yet distinguishable structures. This physical system demonstrates the possibility of controlling the self-assembly of monomer droplets into polymers, which in turn allows us to study their collapse and folding to explore their physical bases from a new perspective.
The authors are: Angus McMullen, Alexander Grosberg, Jasna Brujic.

Almut Burchard
University of Toronto
"Geometry in Wasserstein space: geodesics, gradients, and curvature, from an Eulerian point of view"
The optimal transportation problem defines a notion of distance on the space of probability measures over a manifold, the *Wasserstein space*. In his 1994 Ph.D. thesis, McCann discovered that this space is a length space: the distance between probability measures is given by the length of minimizing geodesics called *displacement interpolants*. A surprising number of important functionals in physics and geometry turned out to be geodesically convex. I will describe recent work with Benjamin Schachter on differentiating functionals (such as the entropy or the Dirichlet integral) along displacement interpolants. Starting from an Eulerian formulation for the underlying optimal transportation problem, we take advantage of the system of transport equations to compute derivatives of arbitrary order, for probability densities that need not be smooth.

Pierluigi Contucci
University of Bologna
"Species and Scales in the Gaussian Spin Glasses"
The seminar will present some generalisation of the Sherrington and Kirkpatrick model where the covariance function is endowed with a multi-scale or a multi-specie structure. Rigorous results will be illustrated and open problems discussed.

Percy Deift
New York University
“On the asymptotic behavior of a log gas in the bulk scaling limit in the presence of a varying external potential”
Abstract. We study the determinant $\det(I - \gamma K_s)$, $0 < \gamma < 1$, of the integrable Fredholm operator $K_s$ acting on the interval $(1, 1)$ with kernel $K_s(\lambda; \mu) = (\sin s(\lambda - \mu)) / (\lambda - \mu)$. This determinant arises in the analysis of a log-gas of interacting particles in the bulk-scaling limit, at inverse temperature $\beta = 2$, in the presence of an external potential $v = -1/2 \ln(1 - \gamma)$ supported on an interval of length $2s/\pi$. We evaluate, in particular, the double scaling limit of $\det(I - \gamma K_s)$ as $s \to \infty$ and $\gamma \to 1$, in the region $0 \leq \kappa = v/s = -1/2 \ln(1 - \gamma) \leq 1 - \delta$, for any fixed $0 < \delta < 1$. This problem was first considered by Dyson in 1995.

**Bertrand Duplantier**
Paris-Saclay University

**“Generalized Integral Means Spectrum of Whole-Plane SLE”**

We describe recent advances in the multifractality of the harmonic measure of Schramm—Loewner Evolution (SLE). We introduce a generalized notion of integral means spectrum, that involves the averaged moments of both the SLE conformal map and its derivative. This formalism in particular allows for a unified description of the spectra of the interior and exterior versions of whole-plane SLE. We establish four analytical forms taken by the generalized spectrum, separated by five phase transition lines in the moment plane. Joint works with Dmitry Belyaev, Ho Xuan Hieu, Le Thanh Binh and Michel Zinsmeister.

**Subhro Ghosh**
National University of Singapore

**“Two manifestations of rigidity in random point sets: forbidden regions and maximal degeneracy”**

A point process is said to be "rigid" if its local observables are completely determined (as deterministic functions of) the point configuration outside a local neighbourhood. For example, it has been shown in earlier work that, in the Ginibre ensemble (a.k.a. the 2D Coulomb gas at inverse temperature beta=2), the point configuration outside any bounded domain determines, almost surely, the number of points in the domain.

In this talk, we will explore two recent manifestations of such rigidity phenomena. For the zeros of the planar Gaussian analytic function, we show that outside every large "hole", there is a "forbidden region" which contains a vanishing density of points. This should be seen in contrast with the corresponding situation for classically understood models (e.g. random matrix ensembles), where no such effects are known to occur.

In the second part of the talk, we will consider "stealthy" hyperuniform systems, which are systems whose structure function (i.e., the Fourier transform of the two-point correlation) vanishes near the origin. We show that such systems exhibit "maximal degeneracy", namely the points outside a bounded domain determine, almost surely, the entire point configuration inside the domain. En route, we establish a conjecture of Zhang, Stillinger and Torquato that such systems have (deterministically) bounded holes. Based on joint works with Joel Lebowitz and Alon Nishry.

**Gian Michele Graf**
ETH Zurich

**“Disorder and topology. The cases of Floquet and of chiral systems”**

We will present a new formulation of bulk and edge indices for disordered Floquet systems. A byproduct is a space-time duality stating the equivalence of two settings: two systems may be placed next to one another in space or operate one after the other in time. A different type of systems to be addressed are
disordered chiral chains, which may be viewed as Su-Schrieffer-Heeger models with random hopping. There localization occurs at all but possibly one energy, which is enough to endow the model with topological features. Different formulations of the index will be introduced and related to the Lyapunov spectrum of the chain.

**Rafael Greenblatt**  
University of Roma Tre  
“Singular behavior of the Lyapunov exponent of a product of random $2 \times 2$ matrices and a related continuous process”  
We consider a certain infinite product of random $2 \times 2$ matrices appearing in the exact solution of some 1 and 1+1 dimensional disordered models in statistical mechanics, which depends on a deterministic real parameter $\varepsilon$ and a random real parameter with distribution $\mu$. For a large class of $\mu$, we prove a prediction by B. Derrida and H. J. Hillhorst (1983) that the Lyapunov exponent behaves like $C \varepsilon^2 \alpha$ in the limit $\varepsilon \to 0$, where $\alpha \in (0,1)$ is determined by $\mu$. The proof is made possible by a contractivity argument which makes it possible to control the error involved in using an approximate stationary distribution similar to the original proposal, along with some refinements in the estimates obtained using that distribution. A limiting procedure gives a continuum process whose leading Lyapunov estimate admits an exact formula, which also allows us to reformulate part of the argument by McCoy and Wu for the presence of an essential singularity in the free energy of the two-dimensional Ising model with columnar disorder. (Joint work with F. Comets, G. Giacomin and G. Genovese)

**Alexander Grosberg**  
New York University  
“From Sisyphus to Boltzmann: an example of repulsive depletion interaction”  
While depletion interaction, e.g., between two plates in an equilibrium system (such as a colloidal solution) is an attraction, we show how colloids driven by a colored Ornstein-Uhlenbeck noise may leave to the counter-intuitive opposite effect. This is due to the accumulation of lackadaisical particles in the gap between plates. The underlying physical effect is the difference between white noise drive, which sets particle energy fluctuations of order $kT$ (Boltzmann limit), and colored noise drive with long persistence time, which controls particle propulsion (“pushing”) force (Sisyphus limit).

**David Huse**  
Princeton University  
“Butterflies: classical and quantum”  
I will discuss the growth or decay and spreading of correlations and perturbations in many-body classical and quantum systems, chaotic and otherwise. We have explored the behavior of different systems in terms of the velocity-dependent Lyapunov exponent and the closely-related Lieb-Robinson velocities. Reference: "Velocity-dependent Lyapunov exponents in many-body quantum, semi-classical, and classical chaos", (Vedika Khemani, David A. Huse and Adam Nahum), arXiv:1803.05902.

**John Imbrie**  
University of Virginia  
“The Anderson model with discrete disorder”

**Vojkan Jaksic**  
McGill University  
“Statistical Mechanics of Repeated Quantum Measurements”
The statistics of the (finite alphabet) outcomes of repeated quantum measurements is studied by methods of thermodynamic formalism. Viewed as one-dimensional spin systems with long range interactions, repeated quantum measurements exhibit very rich (and sometimes very singular) thermodynamic behaviour. We will describe general thermodynamical formalism of these systems and illustrate its unexpected features on a number of examples. This talk is based on joint works with T. Benoist, N. Cuneo, Y. Pautrat, and C-A. Pillet.

**Antti Kupiainen**
University of Helsinki

“Proof of the DOZZ Formula”

In 1994 Dorn and Otto and independently Zamoldzchikov and Zamoldzchikov conjectured a remarkable formula for certain correlation functions of the Liouville theory, a conjectural scaling limit of planar maps. I will discuss a recent proof of this DOZZ formula which is based on novel integrability properties of the Gaussian Multiplicative Chaos. This is joint work with R. Rhodes and V. Vargas.

**Dov Levine**
Technion

“Quantifying Hidden Order Out of Equilibrium”

While the equilibrium properties, states, and phase transitions of interacting systems are well described by statistical mechanics, the lack of suitable state parameters has hindered the understanding of non-equilibrium phenomena in diverse settings, from glasses to driven systems to biology. Here we introduce a simple idea which enables the quantification of organization in non-equilibrium and equilibrium systems, even when the form of order is unknown. The length of a losslessly compressed data file is a direct measure of its information content, $I_c$, which, when the file represents a microstate in equilibrium, is its entropy. I will discuss $I_c$ for some out-of-equilibrium systems, and show that it both identifies ordering and reveals critical behavior in dynamical phase transitions.

**Andrea Liu**
University of Pennsylvania

“How glasses relax and go with the flow”

All solids flow at high enough applied stress and melt at high enough temperature. Crystalline solids flow and premelt via localized particle rearrangements that occur preferentially at structural defects known as dislocations. The population of dislocations therefore controls both how crystalline solids flow and how they melt. In disordered solids, there is considerable evidence that localized particle rearrangements induced by stress or temperature occur at localized flow defects but all attempts to identify them directly from the structure have failed. Here we introduce a novel application of machine learning data mining methods to diagnose flow defects, or “soft” particles from their local structural environments. We follow the softness of each particle as it evolves under deformation or temperature. Our results show that machine learning methods can be used to gain a conceptual understanding that has not been achieved with conventional approaches.

**Bruno Nachtergaele**
University of California, Davis

“Dimerization in a class of SU(n) invariant quantum spin chains.”

We use a random loop representation to prove dimerization in the ground states of a family of SU(n) invariant quantum spin chains. This class of models has been studied in the literature for several decades by a range of methods, which have revealed some rather special properties. Previous results strongly pointed to the occurrence of dimerization and this work provides a direct proof of dimerization for all
sufficiently large values of the spin. I will also discuss results and open problems concerning dimerization in other spin chains. This is joint work with Daniel Ueltschi.

Chuck Newman  
New York University

“Remarks on the Riemann Hypothesis”

One fairly standard version of the Riemann Hypothesis (RH) is that a specific probability density on the real line has a moment generating function (Laplace transform) that as an analytic function on the complex plane has all its zeros pure imaginary. We'll review a series of results that span the period from the 1920's to 2018 concerning a perturbed version of the RH. In that perturbed version, due to Polya, the log of the probability density is modified by a kind of mass term (in quantum field theory language). This gives rise to an implicitly defined real constant known as the de Bruijn-Newman Constant, Lambda. The conjecture and now theorem (Newman 1976, Rodgers and Tao 2018) that Lambda is greater than or equal to zero is complementary to the RH which is equivalent to Lambda less than or equal to zero. We'll briefly discuss some connections with quantum field theory and the Lee-Yang circle theorem.

Ron Peled  
Tel Aviv University

“A power-law upper bound on the correlations in the two-dimensional random-field Ising model”

As an example of the Imry-Ma phenomenon, the addition of an iid quenched random field to the two-dimensional Ising model eliminates the model's famed discontinuity in its magnetization's response to a uniform external field. Thus, even with a weak random field, the 2D Ising model has a unique infinite-volume Gibbs state at all temperatures. This fact may be quantified by considering the decay rate of the effect of boundary conditions on the magnetization in finite systems. This rate is known to be exponentially fast for a strong random field. Our main new result is a power-law upper bound which is valid at all field strengths and at all temperatures, including zero. Our analysis proceeds through a streamlined and quantified version of the Aizenman-Wehr proof of the Imry-Ma rounding effect. Joint work with Michael Aizenman.

Fyl Pincus  
University of California, Santa Barbara

“Effective charge of hydrated ions”

We apply an earlier model for Hydrogen bonds in water to the case of hydrated ions.

In the cartoon above (downloaded from Google Images), the standard picture that the water dipoles are oriented, e.g. with the protons toward anions and vice-versa. This is engendered by the ionic electrostatic potential. However since each program has four possible proton sites (tetrahedral coordination), there are, on average (for bulk water), two protons per oxygen. However for hydration waters near an anion, there is a potential advantage for higher proton occupancy on a given oxygen ion at the cost of Coulomb repulsions with the pre-existing protons. The result is a build-up of positive charge within the hydration layer which renormalizes down the ionic charge.
Dave Pine  
New York University  
“Anomalous diffusion of DNA-coated colloids on a substrate”

Jeff Schenker  
Michigan State University  
“Localization (and resonant delocalization?) of a disordered polaron”  
Polaron models describe the motion of a tracer particle interacting with a quantum field. The Holstein Hamiltonian describes a tight binding particle interacting with a field of harmonic oscillators. We will consider the Holstein Hamiltonian with the addition of on-site disorder in the tracer particle potential. Provided the hopping amplitude for the particle is small, we are able to prove localization for matrix elements of the resolvent, in particle position and in the field Fock space. These bounds imply a form of dynamical localization for the particle position that leaves open the possibility of resonant tunneling in Fock space between equivalent field configurations. Some related deformations of the Anderson model in which we can prove the existence of resonant tunneling will be presented, but the exact nature of the dynamics for the disordered Holstein model remains open. (Joint work with Rajinder Mavi.)

Avy Soffer  
Rutgers University  
“On the Derivation of NLS type Dynamics of Perturbed Bose-Einstein Condensates”  
The large N limit of of N-boson quantum systems can be approximated by nonlinear equations. One choice of perturbation is in fact a (very heavy) other quantum particle interacting with the N-body system. In this case, and assuming the system is at zero temperature, one can then derive a coupled NLS and effective particle dynamics. The second example is a Bose system which is slightly perturbed away from the ground state. The allowed perturbation is however is not too small: In this situation the ratio of the occupation number of the ground-state and the excitation forming the fluctuations will influence the leading order of the dynamics of the system. In this sense we show the validity of the Bogoliubov time evolution in a situation where the temperature has an effect on the dynamics of the system.

Phil Sosoe  
Cornell University  
“The chemical distance in 2D percolation”  
The critical phase of two dimensional Bernoulli percolation is now well understood rigorously, in terms of detailed descriptions at the qualitative level, and even exact computations of critical exponents and scaling limits for some models. One quantity of physical interest which has remained mysterious is the chemical distance, the graph distance inside percolation clusters. I will report on recent this problem with Jack Hanson and Michael Damron.

Prasad Tetali  
Georgia Tech  
“One on the uniqueness/phase-coexistence threshold for the hard-core model on the square lattice”  
It has long been conjectured that on the square lattice $\mathbb{Z}^2$ the hard lattice gas model has a critical value $\lambda_c = 3.796\ldots$ with the property: if $\lambda < \lambda_c$ then it exhibits uniqueness of phase, while if $\lambda > \lambda_c$ then there is phase coexistence – existence of multiple Gibbs measures. I will give a brief update on the status of this problem, highlighting recent efforts that have rigorously established that $\lambda_c$ belongs to the interval $[2.538, 5.3506]$.

Salvatore Torquato  
Princeton University
"Uncovering Multiscale Order in the Prime Numbers via Scattering"

The prime numbers have been a source of fascination for millenia and continue to surprise us. Motivated by the hyperuniformity concept, which has attracted recent attention in physics and materials science, we show that the prime numbers in certain large intervals possess unanticipated order across length scales and represent the first example of a new class of many-particle systems with pure point diffraction patterns, which we call "effectively limit-periodic." In particular, the primes in this regime are hyperuniform. This is shown analytically using the structure factor $S(k)$, proportional to the scattering intensity from a many-particle system, where $k$ is the wavenumber. Remarkably, the structure factor for primes is characterized by dense Bragg peaks, like a quasicrystal, but positioned at certain rational wavenumbers, like a limit-periodic point pattern. We identify a transition between ordered and disordered prime regimes that depends on the intervals studied. Our analysis leads to an algorithm that enables one to predict primes with high accuracy. Effective limit-periodicity deserves future investigation in physics, independent of its link to the primes.

David Vanderbilt  
Rutgers University

“Axion insulators”

Topological insulators such as Bi2Se3 exhibit a quantized orbital magnetoelectric coupling, known as an axion coupling, which is reflected in the presence of a half-integer quantum anomalous Hall response on any gapped surface. However, unless the time-reversal symmetry that protects the bulk topology is broken at the surface, the surface is necessarily metallic and the axion response is hidden. Here I will introduce a broader class of topological crystalline insulators such that the quantized axion coupling is protected by other symmetries, such as inversion, in such a way that the surfaces are naturally gapped. Unfortunately, materials realizations currently remain elusive. Nevertheless, I will present some results of our exploration of simple tight-binding models of such systems, and will describe some of the interesting properties such materials are expected to display, including chiral edge channels flowing along surface steps and facet intersections.

Simone Warzel  
Technical University of Munich

“The hierarchical paradigm in random matrices models”

The Anderson phase transition is a fundamental physical feature of large disordered quantum systems. Among its universal properties are the (de-)localization of eigenvectors of random matrix models as well as the statistics of the corresponding local eigenvalue process. While the localization part of the story is reasonably well understood, much less is known for the regime of delocalization. In this talk, I will report on recent results concerning hierarchical versions of random matrix models for which such a transition can be established.

Peter Winkler  
Dartmouth

“Large Random Permutations”

Permutations admit natural limit structures, together with a variational principle that permits "seeing" what a large random permutation with given characteristics looks like. (Joint work with Rick Kenyon, Dan Kral' and Charles Radin.)

Emil Yuzbashyan  
Rutgers University

“Integrable unitary dynamics and Knizhnik-Zamolodchikov equations”
I will outline a way to make parameters (e.g., the interaction strength) of a quantum integrable model time-dependent without breaking its integrability. Interesting many-body models that emerge from this approach include a Floquet BCS superconductor and the problem of molecular production in an atomic Fermi gas swept through a Feshbach resonance as well as various known models of multi-level Landau-Zener tunneling.

Amazingly, all these models map to spin Hamiltonians known as Gaudin magnets, which, in turn, are intimately related to famous Knizhnikov-Zamolodchikov equations of Conformal Field Theory. I will use this mapping to derive the general solution of the non-stationary Schrodinger equation for each of the above models.

**Riccardo Zecchina**  
Bocconi University

“The out-of-equilibrium landscape of learning algorithms”

Training neural networks is a highly non-convex problem which however can often be solved in practice by variants of Stochastic Gradient Descent. In order to shed light on this phenomenon we have developed a large deviation analysis based on a local entropy measure which has revealed the existence of subdominant and extremely dense regions of optimal solutions which coexist with an exponential number of local minima. These rare dense regions possess two fundamental properties: they are accessible by a multitude of out-of-equilibrium processes and they have good generalization properties. Building on the local entropy measure, we can design several effective stochastic algorithms and find a simple successful application of quantum annealing.

**Ofer Zeitouni**  
Weizmann Institute of Science

“Some results concerning Liouville heat kernel”

I will discuss relations between scaling exponents for Liouville graph distance and heat kernel exponents for Liouville Brownian motion. Joint work with Jian Ding and Fuxi Zhang.