

TIFR Annual Technical Report (2014-15)

Department of Theoretical Physics

Condensed Matter and Statistical Physics

Condensate Formation in the presence of Quenched Disorder

Quenched disorder can strongly affect the occurrence and nature of phase transitions in interacting-particle systems. This was demonstrated for the zero range process (ZRP), the steady state of which can exhibit a transition to a condensate phase in which one site holds a macroscopic number of particles. For a disordered ZRP with capacities chosen from a power-law distribution, conditions for condensate formation were identified in terms of interactions and randomness. Further, there are strong sample to sample fluctuations, and the distribution of the critical density was determined exactly.

[Mustanshir Barma with S. Gupta (LPTMS, Orsay, France, Universite Firenze, Italy and MPI, Dresden, Germany)]

Strong Phase Separation with Rapid Relaxation

In strong phase separation, an ordered phase survives at all temperatures and does not admit droplets of other phases at any temperature. Relaxation to such a strongly ordered phase has been studied in several models, and is found to be logarithmically slow, owing to metastable states whose lifetime diverges exponentially with system size. Numerical simulations supported by analytical arguments show that in a nonequilibrium system of particles sliding down a fluctuating surface, the strongly separated state consists of a stretched particle-holding phase coexisting with a floppy particle-free phase. The system is found to allow algebraic coarsening, much faster than the logarithmic behavior found in other such systems.

[Mustanshir Barma with S. Chakraborty, S. Pal and S. Chatterjee, (S. N. Bose Centre, Kolkata)]

Resonating valence-bond physics on the honeycomb lattice

Bond and spin correlations of the nearest-neighbor resonating valence bond (RVB) wave function for a $SU(2)$ symmetric $S=1/2$ antiferromagnet on the honeycomb lattice were studied. It was found that spin correlations in this wave function are short ranged, while the bond energy correlation function takes on an oscillatory power-law form at the wavevector Q corresponding to columnar valence-bond solid order on the honeycomb lattice. A recently introduced large- g expansion approach was used to relate bond-energy correlators of the $SU(g)$ wave function to dimer correlations of an interacting fully packed dimer model with a three-dimer interaction of strength $V(g)=\ln(1+1/g^2)$. Putting $g=2$, it was numerically found that the dimer correlation function of this dimer model has power-law behavior in rather good agreement with the wave function results. The same quantities were also studied for $g=3,4,10$ and it was found that the bond-energy correlations in the $SU(g)$ wave function are consistently well reproduced by the corresponding dimer correlations in the interacting dimer model.

[Kedar Damle with P. Patil (IITM) and I. Dasgupta (IITB)]

Transitions to valence-bond solid order in a honeycomb lattice antiferromagnet

Quantum Monte Carlo methods were used to study the ground-state phase diagram of a $S=1/2$ honeycomb lattice magnet in which a nearest-neighbor antiferromagnetic exchange J (favoring Neel order) competes with two different multispin interaction terms: a six-spin interaction Q_3 that favors columnar valence-bond solid (VBS) order, and a four-spin interaction Q_2 that favors staggered VBS order. When both multi-spin interactions are larger than J , it was found that competition between the two different VBS orders stabilizes Neel order in a large swath of the phase diagram even when J is the smallest energy scale in the Hamiltonian. It was also established that the Neel-columnar VBS transition is continuous for all values of Q_2 , and that critical properties along the entire phase boundary are well characterized by critical exponents and amplitudes of the noncompact CP^1 (NCCP1) theory of deconfined criticality, similar to what is observed on a square lattice. However, a surprising threefold anisotropy of the phase of the VBS order parameter at criticality, whose presence was recently noted at the $Q_2=0$ deconfined critical point, was seen to persist all along this phase boundary. A classical analogy was used to explore this by studying the critical point of a three-dimensional XY model with a fourfold anisotropy field which is known to be weakly irrelevant at the three-dimensional XY critical point. In this case, it was again found that the critical anisotropy appears to saturate to a nonzero value over the range of sizes accessible to the simulations.

[Kedar Damle with S. Pujari (LPT, University of Toulouse, CNRS and University of Kentucky) and F. Alet (LPT, University of Toulouse, CNRS)]

Pattern formation in the Rotor-router model

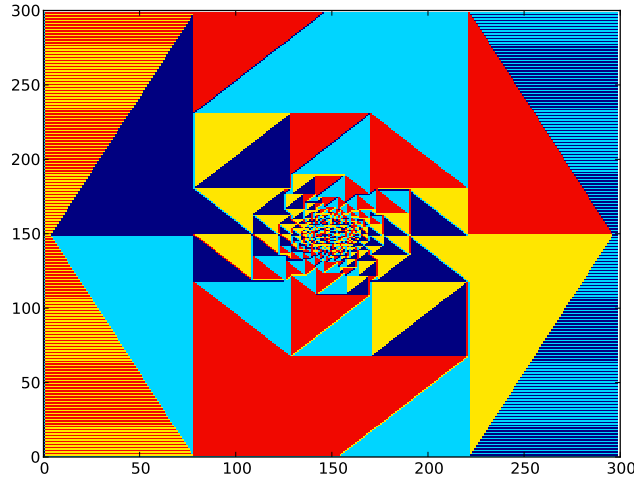


Figure 1: A pattern formed in the rotor-router model : different colors indicate the different directions of arrows at the sites of the lattice, obtained after relaxation after 900 walkers have been introduced at the origin.

The growing patterns in the rotor-router model, formed by adding N walkers at the center of an $L \times L$ two-dimensional square lattice, were studied, starting with a periodic background of arrows, and relaxing to a stable configuration. The pattern is made of a large number of triangular or quadrilateral regions, where in each region all arrows point in the same direction. It was shown that the pattern formed by arrows which have been rotated at least one full circle, may be considered as a tiling of the plane by squares of different sizes. The sizes of these squares grow linearly with N , for $1 \ll N < 2L$. The Brooks-Smith-Stone-Tutte theorem, relating tilings of squares by smaller squares to resistor networks, was used to determine the exact relative sizes of these tiles. The scaling limit of the number of visits $\phi(\xi, \eta)$ as a function of the scaled position (ξ, η) was also determined. Numerical evidence was presented for the fact that deviations of the sizes of the squares in the tiling from the linear growth law are, for finite N , bounded and quasiperiodic functions of N .

[Deepak Dhar and R. Dandekar]

Fragmentation of an ice-sheet by branching and merging cracks

A model of fragmentation of a planar sheet like ice sheet or glaciers was studied. In the model, fragmentation occurs by growth of cracks that move with a velocity in preferred direction, but undergo random transverse displacements as they move. There is a non-zero probability of crack-splitting, and the split cracks move independently. If two cracks meet, they merge, and move as a single crack. In the steady state, there is non-zero density of cracks, and the sheet left behind by the moving cracks is broken into a large number of fragments of different sizes. The evolution operator

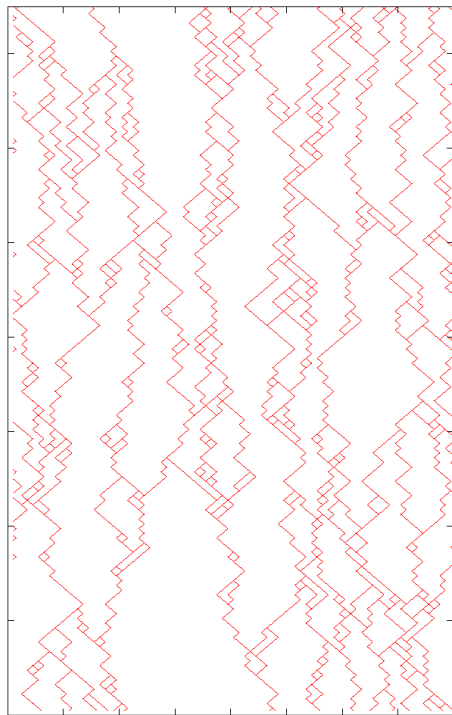


Figure 2: A simulation of the model of fragmentation. The cracks propagate to the right. Note the wide distribution of sizes of fragments.

for this model reduces to the Hamiltonian of a quantum XY spin chain, which is exactly integrable. This was used to determine the steady state, and also the distribution of sizes of fragments.

[Deepak Dhar]

A perturbative renormalization group approach to driven quantum systems

A perturbative momentum shell renormalization group (RG) approach was used to study the properties of a driven quantum system at zero temperature. To illustrate the technique, it was applied to a bosonic ϕ^4 theory with an arbitrary time dependent interaction parameter $\lambda(t) = \lambda f(\omega_0 t)$, where ω_0 is the drive frequency, and the RG flow equations were derived for the system using a Keldysh diagrammatic technique. It was shown that the scaling of ω_0 is analogous to that of temperature for a system in thermal equilibrium and its presence provides a cutoff scale for the RG flow. The resultant RG equations were analyzed to derive an analytical condition for such a drive to take the system out of the gaussian regime, and show that the onset of the non-gaussian regime occurs

concomitantly with the appearance of non-perturbative mode coupling terms in the effective action of the system. These results were alternatively derived from equations of motion of the bosons and their significance for systems near critical points, described by time-dependent Landau-Ginzburg theories, were studied.

[Rajdeep Sensarma with S. De Sarkar and K. Sengupta (IACS)]

Role of trap-induced scales in non-equilibrium dynamics of strongly interacting trapped bosons

A time-dependent hopping expansion technique was used to study the non-equilibrium dynamics of strongly interacting bosons in an optical lattice in the presence of a harmonic trap characterized by a force constant K . It was found that after a sudden quench of the hopping amplitude J across the superfluid (SF)-Mott insulator (MI) transition, the SF order parameter $|\Delta(r, t)|$ and the local density fluctuation $\delta n(r, t)$ exhibit sudden decoherence beyond a trap-induced time scale $T_0 \sim K^{1/2}$. After a slow linear ramp down of J , the order parameter $|\Delta(r)|$ and the boson defect density $P(r)$ was found to display a novel non-monotonic spatial profile. Both these phenomena were explained as consequences of trap-induced time and length scales affecting the dynamics and concrete experimental tests to observe these phenomena was suggested.

[Rajdeep Sensarma with A. Dutta and K. Sengupta (IACS)]

Orbital selective Mott transition in the iron pnictide superconductors

The iron-arsenide superconductors are the newest class of high-temperature superconductors discovered as recently as 2008. The twin issues of the nature of the “normal” state and competing order(s) in the iron arsenides are central to understanding their unconventional, high-temperature superconductivity. It is still an open question whether the normal state properties can be understood as arising from a weakly-correlated itinerant electron perspective or whether strong correlations (Mott physics) play a crucial role. In this joint experiment-theory collaboration, a combination of transport anisotropy measurements on detwinned $SrFe(2-x)Co(x)As_2$ single crystals and LDA+DMFT calculations was used with the purpose of understanding the normal state. The peculiar resistivity anisotropy and its evolution with doping (x) were naturally interpreted in terms of an underlying orbital-selective Mott transition (OSMT) that gaps out the d_{xz} or d_{yz} states. Further, a Landau-Ginzburg approach was used (with a bandstructure plus dynamical mean field theory input to rationalize a wide range of anomalies seen up to optimal doping) that provides strong evidence that an electronic nematic order may be the main competitor to high-temperature superconductivity in the iron arsenides. These findings suggest that strong dynamical fluctuations linked to a quantum-critical point associated with this OSMT and a secondary electronic nematic order constitute a novel and intrinsically electronic glue for high-temperature superconductivity in

the iron-arsenides.

[Vikram Tripathi with S. Das (Cambridge), S. Sebastian (Cambridge), M. Laad (IMSc, Chennai)]

Resonant indirect exchange mechanism for ferromagnetism in magnetic heterostructures

It has been a topic of recent debate whether the indirect exchange mechanism plays a significant role in ferromagnetism of dilute magnetic semiconductors. A nice platform to check this out is modulation-doped magnetic heterostructures, where the magnetic layer containing Mn atoms and the carrier (quantum well) layer with mobile holes are spatially separated by a potential barrier. Despite the smallness of the wavefunction overlap between particles in the two layers, it was found in this work that indirect exchange contribution of the carriers in the quantum well can be significant because of resonant tunnelling effects. Using this model, it was also possible to explain the recent experimental observation that the (ferromagnetic) Curie temperature exhibits a maximum as a function of the depth of the quantum well where the charge carriers reside.

[Vikram Tripathi with I.V. Rozhansky (Ioffe Inst., St. Petersburg), I. V. Krainov, N. S. Averkiev, B. A. Aronzon (Lebedev Inst., Moscow), A. B. Davydov, K. I. Kugel (ITAE, Moscow), E. Lahderanta]

Local moment approach to solve the Hubbard model

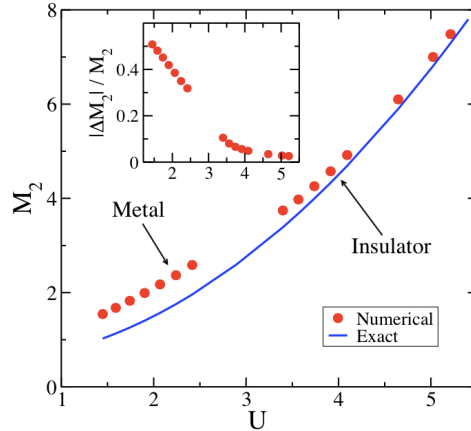


Figure 3: Comparison of the second moment of the spectral function M_2 calculated using LMA with exact sum rule results.

The Hubbard model, a minimalist model that captures electronic correlation physics in a lattice, was investigated using the dynamical mean-field theory (DMFT) at zero temperature, where local moment approach (LMA) was employed semi-analytically to solve the effective impurity model

in the context. The method successfully captures the Mott metal-to-insulator transition at half electron-filling beyond a critical Hubbard interaction strength, and the metallic spectral density obeys the Luttinger pinning condition signifying the Fermi liquid behavior. In contrast to the other impurity solvers, LMA is remarkably useful since it is numerically less expensive and provides excellent agreement with exact sum-rules for the spectral moments at large interaction strength. In addition to this, optical conductivity of the system was calculated using the Kubo formula, and it shows the presence of a universal crossing point (isosbestic point) at various dopings, as seen in many experiments in correlated oxides.

[H. Barman]