TIFR Annual Report 2005-06
THEORETICAL PHYSICS

Condensed Matter and Statistical Physics

Research in this field was conducted in the general areas of non-equilibrium statistical physics, disordered systems, high temperature-superconductivity and strongly correlated systems.

Random Trimer Tilings

Random trimer tilings of a square lattice were studied. Exact numerical diagonalization of transfer matrices was used to determine the correlation length of the system for tilings of cylinders of width up to 24 lattice spacings. It was found that the correlation length grows linearly with width of the cylinder. The random trimer tilings on a plane with open boundary conditions admit a height representation and Monte Carlo simulations indicate that the correlation function grows as $A \ \ log(r)$ for large r. The amplitude A is related to the critical exponents of the theory, which is evidence that the underlying critical theory also has the conformal symmetry. [D. Dhar and A. Ghosh with J.L. Jacobson of LPTMS, Orsay, France]

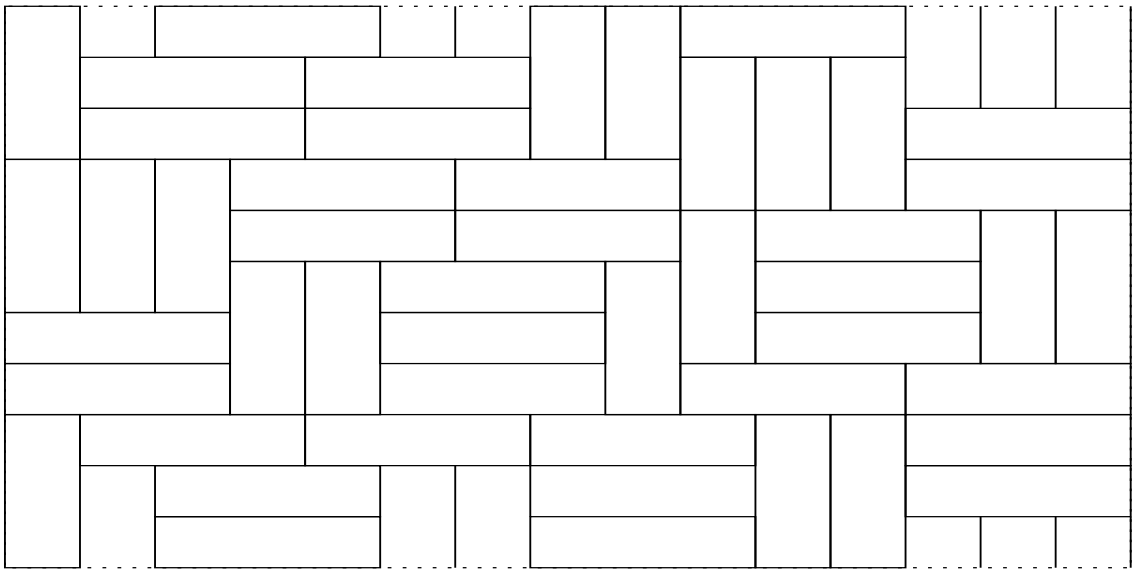

Figure 1: Random Trimer Tilings

Steady State Dynamics of Fluctuations in the Zero-Range Process

The Zero-Range Process (ZRP) is a model of driven diffusive systems. It involves particles hopping between the sites of a lattice, with the rate of hopping depending on the number of particles at the departure site. At long times, the system reaches a nonequilibrium steady state with interesting properties. On tuning the particle density across a critical value, there is a phase transition from a disordered phase with uniform density, to a condensed phase, in which a finite fraction of the total mass resides at one site along with a background at the critical density.

Dynamics in the steady state was studied on a ring by monitoring fluctuations of the particle current across a bond. The integrated particle current was seen to be Poisson-distributed implying that the mean squared fluctuation $C(t)$ grows linearly with time with a known slope. At times which are determined by the system size, $C(t)$ shows oscillations, as a consequence of kinematic waves which transport density fluctuations across the system at a well defined speed. At very large times, $C(t)$ again increases diffusively but the slope scales as the inverse square root of the system size. The crossover between these regimes was studied both numerically and analytically by studying a linearized model. [Shamik Gupta, M. Barma (TIFR) and S. N. Majumdar (LPTMS, Orsay, France)].

Dynamics of a two-component driven system with probe particles

Non-equilibrium driven systems with several species of particles have interesting properties, and can display phase transitions in one dimension, unlike their equilibrium counterparts. A one-dimensional system with two oppositely moving species, with interactions that affect hopping rates, has a steady state which is known to be characterized exactly and shows only short ranged order. However, when probe particles (modeled by vacancies) are introduced, earlier studies have shown that for large values of the interaction strength, there is a phase transition to a state with coexisting particle-rich and particle-poor phases.

Dynamics of this system was studied by investigating the mean squared displacement of tagged particles, of both the charged and probe varieties. Monte Carlo simulations showed that in each case, this quantity is an oscillatory function, with an oscillation period that is proportional to the system size. This can be traced to the existence of two independent kinematic waves in the system, each of which involves density fluctuations of one of the charged species. The propagation speeds, which depend on both the interaction strength and the density, were determined and found to decrease strongly as the system approaches an ordered state. [Sakuntala Chatterjee and M. Barma]

Passive Scalars in Burgers Fluids

Work on passive particles driven by a compressible fluid described by the Burgers equation with noise was continued. A steady state with strong clustering of particles was found;

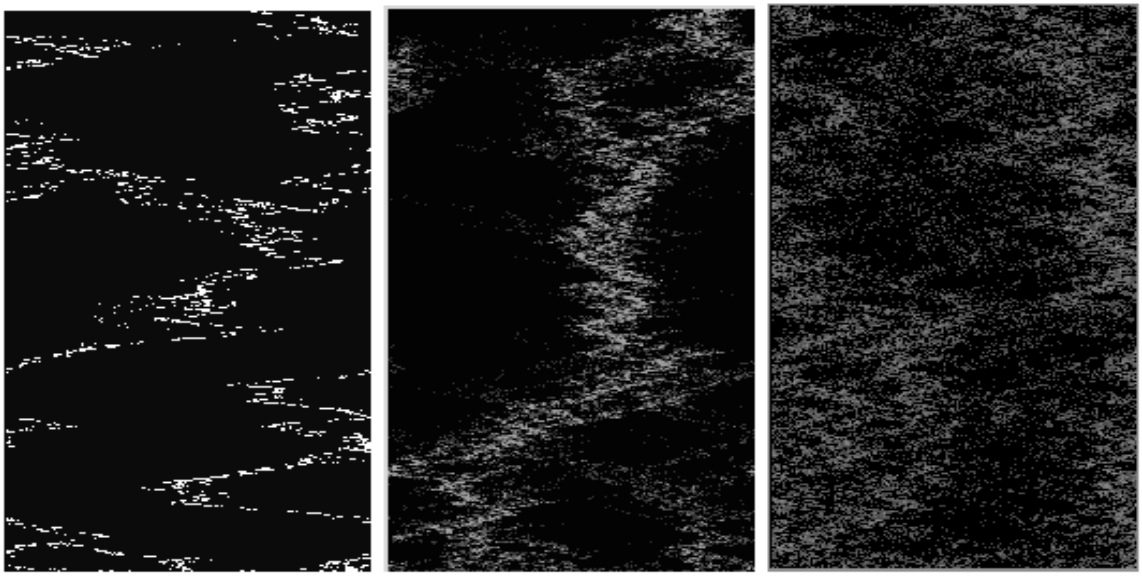

Figure 2: Time evolution of passive particles (shown white) sliding on a fluctuating lattice. The horizontal and vertical axes represent space and time, respectively. The figures show a surface (i) evolving downwards (left) (ii) fluctuating symmetrically (middle) (iii) evolving upwards (right). Fewer, whiter spots indicate a higher degree of clustering (fewer but more dense clusters).

the clusters are highly dynamic, and their mass and locations fluctuate strongly. These fluctuations were shown to remain undamped even in the thermodynamic limit. The problem was also studied in two dimensions and the density-density correlation function was found to be a scaling function of separation and system size. This function diverges at small argument, signalling the occurrence of a strong clustering state, as in one dimension. A mapping relates this problem to that of particles sliding down under gravity on a fluctuating suface evolving downwards. Numerical simulations show that similar clustering is found, though to a lesser quantitative degree, for particles subjected to other related types of forcing, for instance, on surfaces which are evolving upwards, or fluctuating symmetrically (see Figure 2). [Apoorva Nagar, M. Barma (TIFR) and S. N. Majumdar (LPTMS,Orsay, France)]

Granular transport

Granular transport in piles in which particles are added at one end and leave at the other end was studied. It was shown that, as in several 1-dimensional models of ricepiles, the probability distribution of the residence time of grains in the pile of size L has a power-law tail, with the probability that the residence time is greater than t in a pile decaying as $1/t(\ln t)^x$ for $L^\omega \ll t \ll \exp(L^3)$ where x and ω are exponents which take different values depending on whether the residence time is defined as the time the particle stays at one specified site site, or anywhere in the pile.

In a specific model of granular piles, the Oslo ricepile model, the probability of large deviations in height fluctuation of the pile, was studied by Monte Carlo simulation using importance sampling to sample very rare events with probabilities of order 10^{-100}. These simulations fully support the results of our theoretical calculation that the relative frequency of the the state with minimum height, a pile of size L, varies as $\exp(-\kappa L^3)$. The probability distribution function of the height of the pile for different L was also numerically calculated[P. Pradhan and D. Dhar].

Persistent supersolid state of hard-core bosons on the triangular lattice

Hard-core bosons with unfrustrated hopping (t) and nearest neighbour repulsion (U) were studied on the triangular lattice. At half-filling, the system was shown to undergo a zero temperature (T) quantum phase transition from a superfluid phase at small U to a supersolid at $U_c \approx 4.45$ in units of $2t$. This supersolid phase breaks the lattice translation symmetry in a characteristic $\sqrt{3} \times \sqrt{3}$ pattern, and is remarkably stable—indeed, robust arguments indicate that the supersolid phase persists for arbitrarily large U/t, consistent with the results obtained in this study. [D. Heidarian and K. Damle]

Universal relaxational dynamics of gapped one dimensional models in the quantum sine-Gordon universality class

A semiclassical approach to the low-temperature real time dynamics of generic one-dimensional, gapped models in the sine-Gordon model universality class was developed. Using this approach, asymptotically exact universal results for correlation functions were obtained in the temperature regime $T \ll \Delta$, where Δ is the energy gap. [K. Damle and S. Sachdev (Harvard University)]

Spin nematics and magnetization plateau transition in anisotropic Kagome magnets

$S = 1$ kagome antiferromagnets with isotropic Heisenberg exchange J and strong easy axis single-ion anisotropy D were studied. For $D \gg J$, the low-energy physics was described by an effective $S = 1/2$ XXZ model with antiferromagnetic $J_z \sim J$ and ferromagnetic $J_\perp \sim J^2/D$. Exploiting this connection, it was argued that non-trivial ordering into a "spin-nematic" occurs whenever D dominates over J. Experimental signatures of this ordering were analyzed. It was also shown that a magnetic field applied along the easy axis induces a transition to a magnetization plateau state at magnetization 1/3 which breaks lattice translation symmetry due to ordering of the S^z. [K. Damle and T. Senthil (IISC, Bangalore)]