Experimental and Theoretical Developments in Dirty Bosons.

1. V. Gurarie, L. Pollet, N. V. Prokofev, B. V. Svistunov and M. Troyer, Arxiv:0909.4593.

2. E. Altman, Y. Kafri, A. Polkovnikov and G. Refael, Arxiv:0909.4096.

3. M. Pasienski, D. McKay, M. White and B. DeMarco, Arxiv:0908.1183.

4. T. Hong, A. Zheludev, H. Manaka and L.-P. Regnault, Arxiv:0909.1496.

Recommended with a commentary by Thierry Giamarchi, University of Geneva

The combined effect of disorder and interactions is one of the most challenging problem in condensed matter physics. The situation is particularly dramatic for bosons since the noninteracting limit is pathological: all bosons localize by going into the deepest minimum of the random potential, leading to a non-thermodynamic limit (infinite density since a macroscopic number of particles is localized in a finite portion of space). As soon as interactions are included this state cannot survive. In addition pure bosons have naturally a superfluid state, which is normally resistant to the effect of disorder. The competition between disorder and superfluidity (the so-called dirty bosons problem) is thus expected to be quite dramatic.

Although this very challenging problem has been intensively studied for more than 20 years (for references see the introduction of the papers mentioned in the journal club), many challenges remained. In particular:

1. The precise phase diagram was still under debate. This was specially true for the case of one boson per site. For this particular density the interactions, when sufficiently large could lead to an incompressible insulating phase, the Mott insulator. How the presence of such a phase affects the phase diagram, and in particular whether a direct transition between the incompressible Mott insulator and the superfluid is possible was still debated.

2. A good control, either analytical or numerical, on what happens for strong disorder was still lacking.

3. Although there were many systems on which such physics was probed, such as Helium in porous media or Josephson junction arrays, controlled realization were not easy.

Quite remarkably a series of paper on ArXiv have provided important conclusions on these issues.

On the theory side the first paper above addresses the question about the direct transition between the Mott insulator and the superfluid and shows that such a direct transition is impossible due to the existence of rare regions. Such regions always exist at the critical point between a gapped region and a disordered gapless region. Even more importantly than this (quite theoretical) point, new quantum monte-carlo algorithms (so called worm algorithms) are now able to treat quite large systems of bosons. This puts a quantitative determination of the phase diagram within reach even for the case of three dimensional bosons, as is done in this paper, confirming the above result and allowing potentially a direct comparison with the experiments (see below).

Another important step is reported in the second paper, where an analysis of the strongly disordered case is performed, in one dimension, using a real space renormalization group technique developed initially for disordered spin chains. This technique is particularly well adapted for the case of strong disorder (for the case of the disordered spin chain with particle-hole symmetric disorder one can even show that the procedure is asymptotically exact at lower energy scales). One particularly interesting possibility addressed in this paper, is the fact that the weak disorder and the strong disorder might correspond in fact to two different universality classes. This is a very interesting but subtle point that deserves further investigations.

Together with these advances on the theoretical front, two advances on the experimental front were also reported.

One of them (third paper above by Pasienski et al.) concerns a realization of dirty bosons using a cold atomic systems. Indeed cold atoms provide a very controlled realization in which the question of interacting bosons in a random environment can be addressed. Search for the Bose glass phase has already been started using such systems (see e.g. the work of the Florence group: L. Fallani, J. E. Lye, V. Guarrera, C. Fort, and M. Inguscio PRL **98** 130404 (2007)). The experiments by Pasienski et al. are in a three dimensional system of bosons for which the disorder is created using a speckle potential. An additional interesting feature of this experiment is that the existence of the Bose glass phase is tested via its transport properties, by kicking the atomic gas and checking whether transport occurs.Such a measurement of the transport is specially interesting since it gives access to the conducting or insulating nature of the phase in a much more precise way than the simple expansion measurements that have been performed previously. No measurement of the compressibility has however been performed so the experiment cannot distinguish between various kinds of insulators (and in particular between the Bose glass and a commensurate Mott insulator). The phase diagram for the three dimensional system is measured. It is interesting to compare the measured phase diagram (figure 1 of Ref. 3 above) with the theoretical one (figure 1 of first paper above).

Finally a very interesting system to probe for the Bose glass phase was reported in the fourth paper above. The realization of the Bose glass in by Hong et al. is based on a spin system made of coupled dimers. A dimer can be either in a singlet or in (three) triplet state. Under a magnetic field one of the triplet lowers and can cross the singlet level. In the limit where the lowest triplet and the singlet are not too far, one can map the excitations of such a system to a hard core boson system (the absence of a boson is the singlet and the presence of the boson denotes the triplet). Because of the magnetic exchange between the dimers the triplet can delocalize and thus one has an effective system of bosons hopping on a lattice, and interacting via a hard core and nearest neighbor interaction (corresponding to the $S_z S_z$ term in the spin Hamiltonian). The advantage of such bosonic systems are (i) that they are homogeneous, (ii) The density of bosons can be controlled by the magnetic field, which plays the role of a chemical potential and the density of bosons can be directly measured by measuring the magnetization. So the compressibility can be measured. (iii) The phase of the boson corresponds to the angle of the spins in the XY plane perpendicular to the uniformly applied magnetic field. The long range superfluid order corresponds to an antiferromagnetic order in the XY plane. It can thus potentially directly be measured by neutron scattering experiments.

The drawback is of course that the parameters are not flexible and given by the chemistry of the compound. If one can find a compound in which a disordering of the exchange constants can be done, then there is the possibility to study the Bose glass. This is precisely what is reported where a phase with finite compressibility and a rapid decay of the superfluid order has indeed been observed.

One has not exhausted the possibilities of these two, or of similar, experimental systems. They already provide very solid realizations on which to confront the increasingly more quantitative theoretical predictions. Many open questions, besides the simple one of the phase diagram, remain. Dirty bosons physics is a remarkably complex and subtle phenomenon as more than twenty years of research on the Bose glass have amply proved. With these new advances both on the theoretical and experimental front, more fun is to come.