Anderson Localization in Cold Bosonic Atoms.

Density modulations in an elongated BEC released from a disordered potential.
http:// arxiv:0710.1984. Authors: David Clément, Philippe Bouyer, Alain Aspect, and Laurent Sanchez-Palencia.

Disorder-induced trapping versus anderson localization in Bose-Einstein condensates expanding in disordered potentials.
http://arxiv:0803.1774.
Authors: L. Sanchez-Palencia, D. Clément, P. Lugan, P. Bouyer, and A. Aspect.

Effect of interactions on the localization of a Bose-Einstein condensate in a quasiperiodic lattice.
arXiv:cond-mat/0611146
Phys. Rev. A, 75(6):061603, 2007.
Authors:J. E. Lye, L. Fallani, C. Fort, V. Guarrera, M. Modugno, D. S. Wiersma, and M. Inguscio.

Ultracold Atoms in a Disordered Crystal of Light: Towards a Bose Glass.
arXiv:cond-mat/0603655
Phys. Rev. Lett., 98(13):130404, 2007.
Authors: L. Fallani, J. E. Lye, V. Guarrera, C. Fort, and M. Inguscio.

Recommended with a commentary by Thierry Giamarchi, University of Geneva

Anderson localization is a spectacular manifestation of quantum effects in solid state physics. For noninteracting particles interferences due to backscattering can lead to the absence of diffusion and to exponential localization of the wavefunctions. For the case of noninteracting particles we know that disorder leads to exponential localization in one an two dimensions, and to a mobility edge in three dimensions. In one dimension exact solutions and excellent numerical methods are available, so our degree of control and understanding of the problem is excellent. In higher dimensions several questions remain even for the noninteracting case. Getting in practice such a localization is however not so easy. Indeed in solid state electrons do interact, and dropping the interactions, as we would do in a Fermi liquid for example is only a crude starting point, valid in the absence of disorder, or when the disorder is weak enough. One thus turned to the localization of light, or microwaves, for which interactions are truly negligible, but getting into the strongly localized regime is quite difficult.

Even if our understanding of Anderson localization for noninteracting particles is good, as soon as interactions are included, the problem complicates considerably and becomes an important theoretical challenge.

For fermions the interplay of interactions and disorder is known to lead to strong effects . Even more interesting is the case of bosons. In such case, the noninteracting limit cannot serve as a reliable starting point. Indeed in the absence of interactions 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. Quite generally one can expect a transition between a superfluid phase if the interactions are moderately repulsive to a localized phase of Bosons (Bose glass) when the interactions become strong. Probing such physics, especially in low dimensions, is an extremely challenging issue. Condensed matter systems are quite limited from that point of view given the difficulty to obtain bosons, not even to mention putting them in controlled disordered environments, with potential realizations such as Helium in porous media or Josephson junction arrays.

For the above mentioned problems there was thus considerable promise offered by the cold atomic systems. In that case bosons are more the rule than the exception. They can be cooled very well (compared, for the moment, to fermions) and the degree of interactions can be controlled as well. They thus seem perfect systems to tackle the question of Anderson localization with or without interactions. Indeed several proposal were made on how to investigate this question, and at the moment, the two groups of A. Aspect and M. Inguscio have already shown considerable success. Several papers of these groups can be found in the various journals of the cold atom community and the papers given here are just a representative sample of their activity. I can only encourage the readers to further look at the respective bibliographies.

The group of A. Aspect has mostly concentrated in producing the disorder with a laser speckle (see Clement et al. and Sanchez et al. above (and references therein). The condensate of bosons they use is quite anisotropic and can be considered in the one dimensional limit. The atoms are initially prepared in a trap and then allowed to expand through the speckle potential. In the expansion the dilution renders the interactions between the bosons totally ineffective and thus one can truly consider that one deals with essentially non interacting particles, and thus the localization of matter waves. The initial interactions existing before the expansion are thus cleverly used to provide an initial speed to the bosons. Such systems are thus ideally suited to tackle the question of localization of noninteracting particles. Indeed stopping of the propagation of the expansion has been observed. The challenge with such a system is of course to control the strength of the disorder to avoid the fragmentation of the condensate by too strong disorder. Feasibility of observing the strong localization with such system has been demonstrated . Ultimately of course the interest of this system will be to move to other geometries for the case of noninteracting particles or to the much more challenging problem of the localization of the interacting bosons and the Bose glass phase.

The group of M. Inguscio (in the two other papers recommended above) worked mostly with a system in which interactions can be controlled and kept strong from the start by putting the bosons in an optical lattice, realizing a Bose-Hubbard model (one dimensional in the case of the existing experiments) whose kinetic energy (and thus the ratio of interactions/kinetic energy) can be controlled at will. The presence of this optical lattice allows for the case of weak kinetic energy to obtain a Mott insulator of bosons, where one has exactly one boson per site. To impose the "disorder" they used the clever idea of adding another optical lattice with an incommensurate period with the first one. Changing the strength of this second optical lattice allows to play at will with the strength of the "disorder". Indeed increasing the strength of the second lattice they could observe that the gap due to the Mott insulating phase was destroyed. The resulting compressible phase should logically be the Bose glass phase, but identifying it unambiguously would need a probe of its "transport" properties. In fact in these experiments one is not exactly probing a disordered system. The presence of two incommensurate periodic lattices realizes a quasiperiodic potential (the so called Harper potential in that case). It is known, for infinite systems, that quasiperiodic and disordered systems have different diffusion properties and this difference persists in one dimension when interactions are included. However the cold atomic systems are very different from homogeneous, infinite systems, in particular due to the presence of the confining potential keeping the atoms inside the trap. These experiments pose the very interesting question of the properties of interacting bosons in such incommensurate potentials and have started a flourish of theoretical activities to analyze such issues, and in particular the similarities and differences with the disordered systems and the Bose glass.

Both systems have thus made spectacular progress in the experimental realization of interacting bosons in disordered or quasiperiodic potentials and offer very strong promises for the future each with their own strengths and weaknesses. Both have already stimulated many theoretical activities to compute the effects to understand the physics for the particular situation of the atomic gases (trap, spectrum of the speckle, etc.), and I am certain that many more results, both experimental and theoretical will come from this direction.