Popular science account of

Cluster Luttinger Liquids of Rydberg-Dressed Atoms in Optical Lattices

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Quantum physics allows for a large variety of phenomena which in our daily experience of nature are masked by thermal effects. This is the reason why, for example, a gas of atoms at room temperature is well described by a simple classical thermodynamical model.
Nowadays, the observation of exotic quantum effects is possible thanks to the possibility of cooling clouds of atoms down to temperatures much lower than the coldest temperature in the Universe.
In addition, counter-propagating laser beams can create periodic potentials, called optical lattices, with equally spaced local minima (valleys) onto which atoms will prefer to sit. Quantum mechanics allows even for the possibility for atoms to tunnel through the energy barrier of the periodic potential and move from one to the neighbouring lattice site.

In this way, quantum systems can be created which model, e.g., the behaviour of electrical conductors such as copper: the simplest of these models considers a lattice of positively charged ions which creates a potential "seen" by a sea of interacting electrons (in the laboratory these are simulated by our laser cooled atoms) that move freely.

The high degree of control over the properties of the optical lattices allows us even to change the dimensionality of the system under investigation, from the usual three-dimensional to, e.g., one-dimension. Here, atoms 'live' in a tube and intriguing phenomena can emerge, like the fact that, in contrast to any higher dimensional case, each atom has to 'push' the others in order to move because it cannot simply go around them. This is one of the key results of the Tomonaga-Luttinger liquid (TL) theory, whose universality has already been proven for several different 1D systems.

In this work we show how, for a particular shape of interactions that is extended up to a certain cut-off distance, atoms can manifest properties which go beyond predictions of the standard TL theory. The appearance of bubbles of atoms (which is surprising given that we only consider purely repulsive interactions) separated by empty lattice sites, for example, breaks the periodicity of the lattice and changes the properties of the gas with respect to the local (onsite) interacting case. We have developed a new modified TL theory which explains our results from numerical simulations, and we propose an experiment with Rydberg atoms in order to test such predictions.