Popular science account of

Engineering correlations on demand using Rydberg atoms

By Maria Martínez Valado

Understanding and predicting the behaviour of natural systems has been one of the core scientific interests along human history. In this sense, the analysis of correlations – which represent the degree of relationship between two physical observables – has been revealed as an effective way to obtain information on the properties and evolution of an assembly of many particles. For instance, in atomic clouds, correlations arising from the interactions between the individual atoms become relevant because a tiny change on them may have dramatic effects on the evolution of the whole system. In order to study the effects of those strong correlations, it becomes necessary to have a high degree of control of the system of study. In our laboratory, we are able to engineer such strongly correlated systems using Rydberg atoms - atoms with their outermost electron in a highly excited orbit –, whose properties are ideal for such investigations: the lifetimes of Rydberg atoms can be hundreds of microseconds, and they interact strongly with each other even at several micrometers of distance.

We make use of the latter property to study how these interactions enhance the generation of new Rydberg excitations and the correlations arising as a consequence. To do so, we irradiate the atomic sample with an off-resonant laser field, under which a pair of atoms can be excited contemporaneously only if the distance between them is such that interactions compensate the energy difference between the Rydberg state and the laser field (the so-called detuning). Moreover, once a Rydberg excitation is present in the sample, other ground state atoms located at the right distance can be shifted into resonance due to the interactions with the former one, leading to a sequential excitation process. The effect of the interactions becomes visible through an asymmetry when the mean number of Rydberg excitations is plotted as a function of the detuning. Since the off-resonant excitation condition requires that the interactions match not only the same value but also the same sign as that of the energy difference (positive in our case), and we observe an asymmetric line shape towards positive values of the detuning, we interpret this result as a clear sign of the off-resonant excitation process.

A more detailed investigation is possible by analyzing the full counting statistics of the excitation events, namely the probability of detecting a certain number of excitations in a single experiment. In our case, this analysis reveals the strongly correlated nature of the off-resonant Rydberg excitation process through, for instance, a bimodal shape of the histograms of the counting distributions. We make use of these tools to study our system under dissipative conditions (where spontaneous decay from the Rydberg state becomes important). In this regime we find signatures of two different dynamical phases with a transition region in between, where both phases coexist.