Popular science account of

Dipole-mediated energy transport in cold Rydberg clouds

By Vladislav Gavryusev

Man's desire to understand the world we live in has been the leading force in our quest for knowledge and to improve our life, and, as science and technology progress, it is possible to understand in increasing detail the precise mechanisms of nature. One such important, and still largely unanswered, question is how photosynthesis, a key process in plants biology, works. We still don't know how exactly the energy, produced from the absorption of light in one part of a so-called light-harvesting complex, is transported to another position where the next step of photosynthesis happens. One thing we do know, however, is that this energy transport process is governed by dipolar interactions and by the influence of the surrounding environment. The ability to observe single particles with high spatial and temporal resolution is a precious tool to tackle such long standing question, and the group of Prof. Matthias Weidemüller has set on and demonstrated a new method which allows to simulate and to observe the dynamics in light harvesting complexes.

In our experiments, which realize a kind of "quantum simulator", the behavior of the molecules is mimicked by an ensemble of controlled atoms in an electronically highly excited state, called Rydberg atoms. Such atoms are suitable because they exhibit strong interactions, making them good building blocks to simulate processes such as energy transport that involve long-range interactions,

Unfortunately, Rydberg atoms cannot be easily detected with current methods, so we developed a new tool to probe the system, called Interaction Enhanced Imaging. It relies on the clever combination of the strong interactions between Rydberg atoms and a quantum effect called electromagnetically induced transparency (EIT) which inhibits the absorption of light by a cloud of atoms. In a first step a small number of atoms, conventionally called impurities, is excited from the ground state of the atoms to a Rydberg state by a combination of red and blue laser beams. After that, the remaining atoms are rendered transparent to red light using another set of laser beams which excites a different Rydberg state, called the "probe state". The interaction between these two types of Rydberg atoms makes them less transparent, leading to localized absorption spots of the red beam, each containing one impurity atom, that finally are recorded on a CCD camera.

Using this innovative method, we observed that the impurities, initially excited in a small spot, expand outwards until they fill the bigger volume. In this way we were able to find out that the expansion is driven by the dipolar interaction between the two types of Rydberg atoms which transforms one into the other. At the same time, this "atom state hopping" is counteracted by the measurement via Interaction Enhanced imaging of the position of the atoms, since in Quantum Mechanics the process of measurement affects the system under observation. The interplay of these two effects leads to a diffusion of the impurity Rydberg atoms which obeys classical laws.

Such behavior is remarkably similar to the energy transport process that happens in Light Harvesting Complexes because the motion is governed by dipolar interactions and by the influence of the surrounding environment, mimicked by the atoms under EIT. Thanks to the high control achieved over the system, our research can lead to new insights into the processes governing photosynthesis. In future experiments we will try to change the dynamics from classical to quantum and to observe how the system responds.

Ref.: G. Günter *et al.*, Science **342**, 954 (2014)