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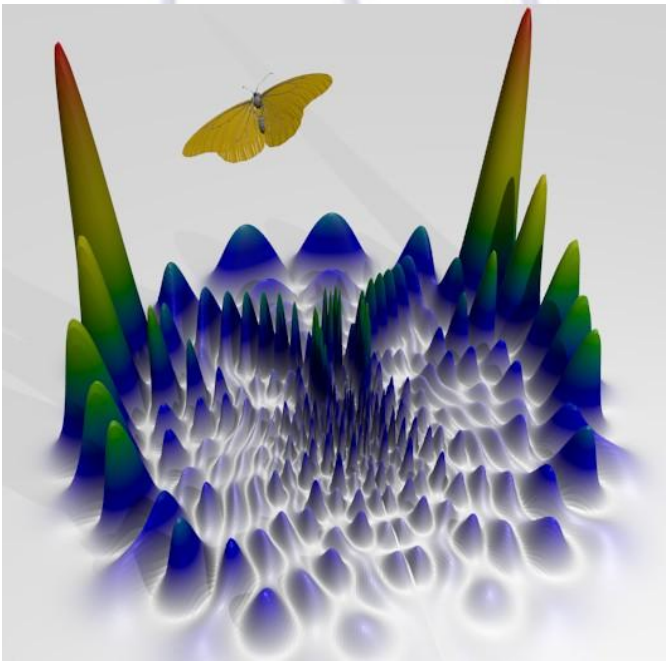
Rydberg-ground state interaction in the ultracold regime

An ever increasing interest in the interaction of Rydberg atoms with surrounding ground state atoms of ultracold samples was triggered by the first experimental proof of Rydberg molecules [1]. These peculiar molecules are bound by a previously unknown type of chemical bond that relies on the scattering between the Rydberg electron and a ground state perturber inside the Rydberg wave function. Apart from the already observed ultra-long range Rydberg molecules that arise in the well- separated low-l states, the very exotic so-called trilobite and butterfly states are also predicted to exist in rubidium [2]. While indications of the former have already been seen experimentally [3], a direct evidence for the latter was so far missing.

Summarizing our recent experiments, I will report on ultra-long range Rydberg molecules and exotic butterfly Rydberg molecules. I will highlight the role of the hyperfine interaction in the perturber atom and how the molecular coupling can be used to change the perturbers spin state upon excitation. Furthermore, I will show that such molecular states can be a useful probe for many-body properties and how they can be used to study the superfluid to Mott insulator transition in optical lattices.



Electron density of a butterfly Rydberg molecule with a bond length of 205 Bohr radii.

Extending the topic to exotic high-l molecules, I will present the first experimental proof for the existence of butterfly Rydberg molecules and highlight their unique properties, such as a tunable bond length, the availability of multiple vibrational ground states and giant dipole moments of hundreds of Debye. Contrary to previous studies, we are able to resolve the rotational structure of the Rydberg molecules and observe pendular states with an unprecedented degree of orientation in small electric fields. This allows us to precisely extract the bond length and to map out the radial nodes of the Rydberg *P*-state wave function.

[1] Bendkowsky et al.: “Observation of ultralong-range Rydberg molecules”, Nature **458**, 1005-1008 (2009)
[2] Hamilton et al.; “Shape-resonance-induced long-range molecular Rydberg states”, J. Phys. B, **35**, L199-L206 (2002)
[3] Booth et al.: “Production of trilobite Rydberg molecule dimers with kilo-Debye permanent electric dipole moments”, Science 348, 99-102 (2015)

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