Using trilobite-like Rydberg trimers to probe Efimov states

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Synopsis We investigate how Rydberg electrons can shed light on the wave function of Efimov states. In 1970, V. Efimov predicted that a system with three particles may have a large number of trimer bound states even when the dimer potential does not posses any bound states. The first Efimov bound state was detected in ultracold Cs atoms in 2006, and in other species since. The three-body bound state is spatially extended, and trilobite-like Rydberg trimers provide the long-range extent appropriate to probe Efimov states. We show how excitations to trilobite-like trimer states correlated to different Rydberg levels n give a specific signature if the three atoms are bound into an Efimov state.

In 2000, Greene and co-workers [1] predicted the existence of extended bound states between Rydberg-ground state atom pairs, so called *trilobite*-like states.

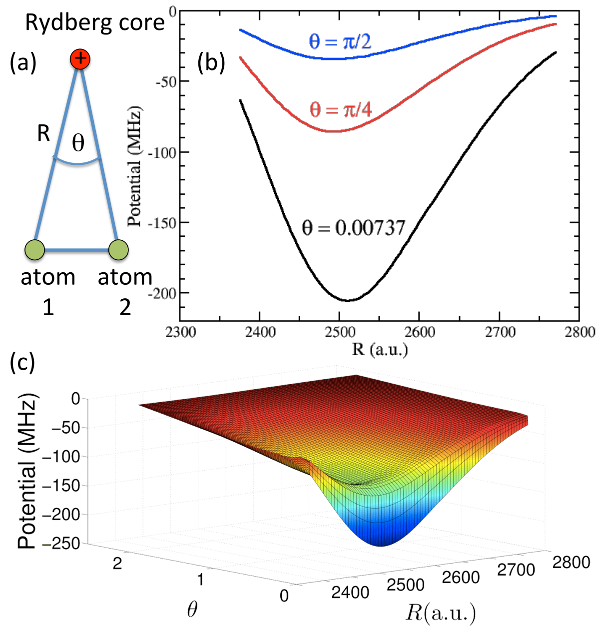

Figure 1. Top: (a) Trimer geometry: both scatterers separated by R from the Rydberg core defining θ. (b) Trimer Rydberg trilobite-like outer potential well for Rb(39p) and s-scattering vs R for three angles. (c) Surface corresponding to (b) vs R and θ.

We generalize this idea to one Rydberg and two ground state atoms using a non-perturbative approach to obtain trilobite-like trimer bound states. Fig.1 shows a sizable θ-dependence for a Rb(39p) s-wave electron in a triangular geometry. Trilobite-like trimers offer a unique probe to study the wave function of Efimov states [see Fig.2(a)]. Adopting a simple model [2] for negative atom-atom scattering length ($a<0$), an Efimov state appears for $a=a_1^- \approx -9.5\,R_{\rm vdW}$, and for $a_2^- = e^{\pi/s_0}a_1^-$, $a_3^- = e^{2\pi/s_0}a_1^-$ and so on ($s_0 = 1.00624$), where $R_{\rm vdW} = \frac{1}{2}(2\mu_2 C_6/\hbar^2)^{1/4}$, with μ_2 and C_6 being the two-body reduced mass and van der Waals coefficient [see Fig.2(c)].

Fig.2(b) depicts how photoassociation (PA) of the Efimov state Ψ into the trilobite state, which depends on the overlap of both wave functions, can probe Ψ. By varying the Rydberg level n, the PA-rate maps Ψ. We discuss how the exact pattern of the PA-rate gives a clear signature of Efimov states.

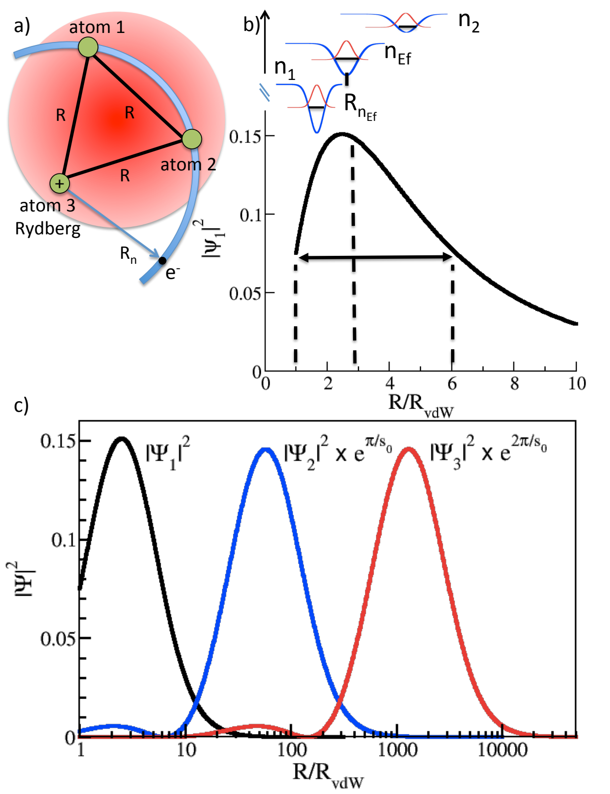

Figure 2. (a) Sketch of an Efimov bound state (red circle). One atom is excited into a Rydberg state, with the electron scattering off both other atoms. (b) First Efimov state wave function peaking at $\sim 3\,R_{\rm vdW}$, and the Rydberg trilobite-like wave function probing it. (c) Comparison of the first three Efimov states: $|\Psi_2|^2$ and $|\Psi_3|^2$ are multiplied by $e^{\pi/s_0} \approx 22.7$ and $e^{2\pi/s_0} \approx 22.7^2$.

References

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