Ultra-long-range molecule engineering via Rydberg-dressing

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In 2000, the three seminal papers launched a new era in Rydberg physics, predicting the blockade mechanism [1], exploring Rydberg dressed interactions [2], and foreseeing trilobite-like molecules [3]. Here, we explore how a new binding mechanism between ground state atoms, based on Rydberg-dressing, can lead to ultra-long-range molecules. We show that by using far-detuned lasers to couple a small but adjustable Rydberg component to the ground state atom, localized long-range potential wells can be created that can support molecular bound levels (Fig. 1).

We consider dressing with s, p, and d Rydberg states using different photon polarizations. We find that each type can sustain bound levels, with linear polarization leading to larger binding energies. We also extend the treatment to polyatomic systems. Fig. 2 shows the BO-PES for a two-color dressing scheme, with one laser dressing with $30p_3/2$, and another with $35p_3/2$. The potential exhibits two minima at $R \approx 1400$ a.u. ($\theta = 0$ and $\pi$), and another at $R \approx 2000$ a.u. ($\theta \approx \pi/2$). The 3D-plot depicts the wells in space based on the azimuthal symmetry of the system. This configuration could sustain a tetramer state, with one atom in the center, one in the torus, and one in each sphere.