Rice lab mimics Jupiter's Trojan asteroids inside a single atom

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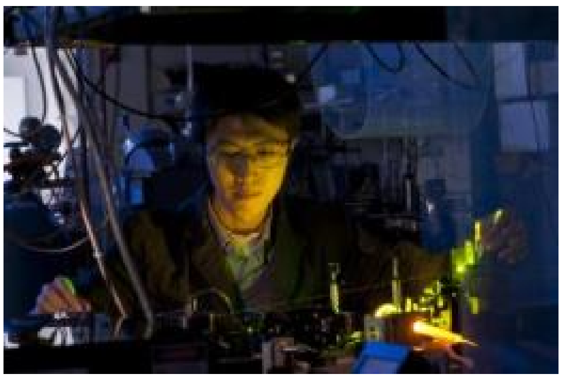

Rice University graduate student Shuzhen Ye used an ultraviolet laser to create a Rydberg atom in order to study the orbital mechanics of electrons. Credit: Jeff Fitlow/Rice University

Rice University physicists have gone to extremes to prove that Isaac Newton's classical laws of motion can apply in the atomic world: They've built an accurate model of part of the solar system inside a single atom of potassium.

In a new paper published this week in *Physical Review Letters,* Rice's team and collaborators at the Oak Ridge National Laboratory and the Vienna University of Technology showed they could cause an electron in an atom to orbit the nucleus in precisely the same way that Jupiter's Trojan asteroids orbit the sun.

The findings uphold a prediction made in 1920 by famed Danish physicist Niels Bohr about the relationship between the then-new science of quantum mechanics and Newton's tried-and-true laws of motion.

"Bohr predicted that quantum mechanical descriptions of the physical world would, for systems of sufficient size, match the classical descriptions provided by Newtonian mechanics," said lead researcher Barry Dunning, Rice's Sam and Helen Worden Professor of Physics and chair of the Department of Physics and Astronomy. "Bohr also described the conditions under which this correspondence could be observed. In particular, he said it should be seen in atoms with very high principal quantum numbers, which are exactly what we study in our laboratory."

Bohr was a pioneer of quantum physics. His 1913 atomic model, which is still widely invoked today, postulated a small nucleus surrounded by electrons moving in well-defined orbits and shells. The word "quantum" in quantum mechanics derives from the fact that these orbits can have only certain well-defined energies. Jumps between these orbits lead to absorption or emission of specific amounts of energy termed quanta. As an electron gains energy, its quantum number increases, and it jumps to higher orbits that circle ever farther from the nucleus.

In the new experiments, Rice graduate students Brendan Wyker and Shuzhen Ye began by using an ultraviolet laser to create a Rydberg atom. Rydberg atoms contain a highly excited electron with a very large quantum number. In the Rice experiments, potassium atoms with quantum numbers between 300 and 600 were studied.

"In such excited states, the potassium atoms become hundreds of thousands of times larger than normal and approach the size of a period at the end of a sentence," Dunning said. "Thus, they are good candidates to test Bohr's prediction."

He said comparing the classical and quantum descriptions of the electron orbits is complicated, in part because electrons exist as both particles and waves. To "locate" an electron, physicists calculate the likelihood of finding the electron at different locations at a given time. These predictions are combined to create a "wave function" that describes all the places where the electron might be found. Normally, an electron's wave function looks like a diffuse cloud that surrounds the atomic nucleus, because the electron might be found on any side of the nucleus at a given time.

Dunning and co-workers previously used a tailored sequence of electric field pulses to collapse the wave function of an electron in a Rydberg atom; this limited where it might be found to a localized, comma-shaped area called a "wave packet." This localized wave packet orbited the nucleus of the atom much like a planet orbits the sun. But the effect lasted only for a brief period.

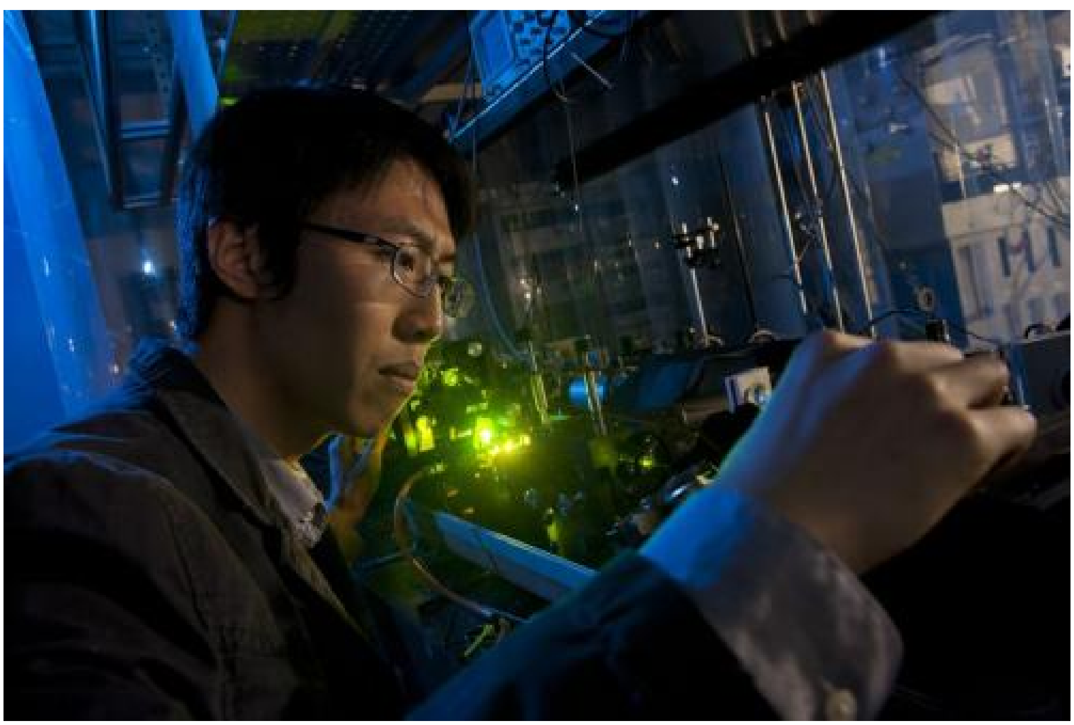

Image: Jeff Fitlow/Rice University

"We wanted to see if we could develop a way to use radio frequency waves to capture this localized electron and make it orbit the nucleus indefinitely without spreading out," Ye said.

They succeeded by applying a radio frequency field that rotated around the nucleus itself. This field ensnared the localized electron and forced it to rotate in lockstep around the nucleus.

A further electric field pulse was used to measure the final result by taking a snapshot of the wave packet and destroying the delicate Rydberg atom in the process. After the experiment had been run tens of thousands of times, all the snapshots were combined to show that Bohr's prediction was correct: The classical and quantum descriptions of the orbiting electron wave packets matched. In fact, the classical description of the wave packet trapped by the rotating field parallels the classical physics that explains the behavior of Jupiter's Trojan asteroids.

Jupiter's 4,000-plus Trojan asteroids -- so called because each is named for a hero of the Trojan wars -- have the same orbit as Jupiter and are contained in comma-shaped clouds that look remarkably similar to the localized wave packets created in the Rice experiments. And just as the wave packet in the atom is trapped by the combined electric field from the nucleus and the rotating wave, the Trojans are trapped by the combined gravitational field of the sun and orbiting Jupiter.

The researchers are now working on their next experiment: They're attempting to localize two electrons and have them orbit the nucleus like two planets in different orbits.

"The level of control that we're able to achieve in these atoms would have been unthinkable just a few years ago and has potential applications in, for example, quantum computing and in controlling chemical reactions using ultrafast lasers," Dunning said.

More information: Paper online: prl.aps.org/abstract/PRL/v108/i4/e043001

Provided by Rice University