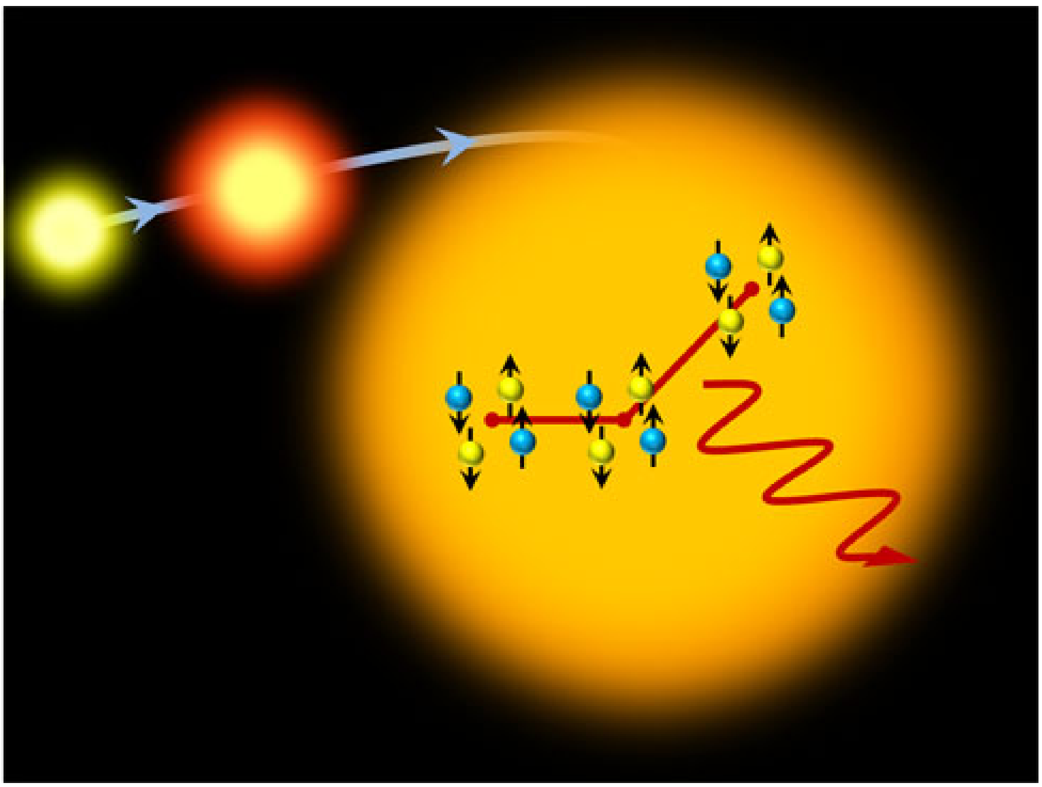
Researchers reveal structure of carbon's 'Hoyle state'

December 10 2012



Alpha clusters in the Carbon-12 nucleus forming a "bent arm" shape.

(Phys.org)—A North Carolina State University researcher has taken a "snapshot" of the way particles combine to form carbon-12, the element that makes all life on Earth possible. And the picture looks like a bent arm.

Carbon-12 can only exist when three alpha particles, or helium-4 nuclei, combine in a very specific way. This combination is known as the Hoyle state. NC State physicist Dean Lee and German colleagues Evgeny Epelbaum, Hermann Krebs and Ulf-G. Meissner had previously confirmed the existence of the Hoyle state using a numerical lattice that allowed the researchers to simulate how the protons and neutrons interact. When the researchers ran their simulations on the lattice, the Hoyle state appeared together with other observed states of carbon-12, proving the theory correct from first principles.

But they also wanted to find out how the nucleons (the protons and neutrons inside the nucleus of an atom) were arranged inside the nucleus of carbon-12. This would enable them to "see" the structure of the Hoyle state. Using the same lattice, the researchers, along with collaborator Timo Laehde, found that carbon-12's six protons and six neutrons formed three "alpha clusters" of four nucleons each. At low energy, the alpha clusters tended to clump together in a compact triangular formation. But for the Hoyle state, which is an excited energy state, the three alpha clusters combined in a "bent arm" formation.

The researchers' findings will appear this month in Physical Review Letters.

"It's interesting that a straight chain seems not to be the preferred configuration for the Hoyle state," Lee says. "A bend in the chain seems necessary. This work leads us to the question of what other nuclei have such alpha cluster shapes. These would be rather exotic structures in nuclear physics and open some really interesting questions regarding shape and stability. For example, can we have longer chains of alpha clusters? We are investigating these possibilities."

More information: "Structure and Rotations of the Hoyle State" *Physical Review Letters*, 2012.

Abstract
The excited state of the 12C nucleus known as the "Hoyle state" constitutes one of the most interesting, difficult and timely challenges in nuclear physics, as it plays a key role in the production of carbon via fusion of three alpha particles in red giant stars. In this letter, we present ab initio lattice calculations which unravel the structure of the Hoyle state, along with evidence for a low-lying spin-2 rotational excitation. For the 12C ground state and the first excited spin-2 state, we find a compact triangular configuration of alpha clusters. For the Hoyle state and the second excited spin-2 state, we find a "bent-arm" or obtuse triangular configuration of alpha clusters. We also calculate the electromagnetic transition rates between the low-lying states of 12C.

Provided by North Carolina State University