PHYS ORG

Carbon, carbon everywhere, but not from the Big Bang

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As Star Trek is so fond of reminding us, we're carbon-based life forms. But the event that jump-started the universe, the Big Bang, didn't actually produce any carbon, so where the heck did it – and we – come from? An NC State researcher has helped create supercomputer simulations that demonstrate how carbon is produced in stars, proving an old theory correct.

More than 50 years ago, an astronomer named Fred Hoyle deduced that when three helium nuclei – or alpha particles – come together inside the core of a star, they have difficulty combining to form carbon-12, the stuff we're made of. So he predicted a new state of carbon-12, one with an energy tuned just right to make the formation of carbon possible in stars. This new state is now known as the Hoyle state. Later experimentation demonstrated that the theory was correct, but no one had ever been able to reproduce the Hoyle state from scratch, starting from the known interactions of protons and neutrons. If the Hoyle state didn't show up in those calculations, then the calculations must be incorrect or incomplete.

NC State physicist Dean Lee, along with German colleagues Evgeny Epelbaum, Hermann Krebs, and Ulf-G. Meissner, had previously developed a new method for describing all the possible ways that protons and neutrons can bind with one another inside nuclei. This "effective field theory" is formulated on a complex numerical lattice that allows the researchers to run simulations that show how particles interact. When the researchers put six protons and six neutrons on the lattice, the Hoyle state appeared together with other observed states of carbon-12, proving the theory correct from first principles.

"We've had simple models of the Hoyle state using three alpha particles for a long time, but the first principles calculations weren't giving anything close," Lee says. "Our method places the particles into a simulation with certain space and time parameters, then allows them to do what they want to do. Within those simulations, the Hoyle state shows up."

Their research appears in the May 13 issue of Physical Review Letters.

Lee adds, "This work is valuable because it gives us a much better idea of the kind of 'fine-tuning' nature has to do in order to produce carbon in stars."

More information: "Ab initio calculation of the Hoyle state" Published: May 9 in *Physical Review Letters*.
prl.aps.org/abstract/PRL/v106/i19/e192501

Abstract
The Hoyle state plays a crucial role in the helium burning of stars heavier than our Sun and in the production of carbon and other elements necessary for life. This excited state of the carbon-12 nucleus was postulated by Hoyle as a necessary ingredient for the fusion of three alpha particles to produce carbon at stellar temperatures. Although the Hoyle state was seen experimentally more than a half century ago nuclear theorists have not yet uncovered the nature of this state from first principles. In this Letter we report the first ab initio calculation of the low-lying states of carbon-12 using supercomputer lattice simulations and a theoretical framework known as effective field theory. In addition to the ground state and excited spin-2 state, we find a resonance at -85(3) MeV with all of the properties of the Hoyle state and in agreement with

the experimentally observed energy.

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