Fundamental question on how life started solved?

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For carbon, the basis of life, to be able to form in the stars, a certain state of the carbon nucleus plays an essential role. In cooperation with US colleagues, physicists from the University of Bonn and Ruhr-Universitat Bochum have been able to calculate this legendary carbon nucleus, solving a problem that has kept science guessing for more than 50 years.

The researchers published their results in the coming issue of the scientific journal Physical Review Letters.

"Attempts to calculate the Hoyle state have been unsuccessful since 1954," said Professor Dr. Ulf-G. Meißner (Helmholtz-Institut für Strahlen- und Kernphysik der Universität Bonn). "But now, we have done it!" The Hoyle state is an energy-rich form of the carbon nucleus. It is the mountain pass over which all roads from one valley to the next lead: From the three nuclei of helium gas to the much larger carbon nucleus. This fusion reaction takes place in the hot interior of heavy stars. If the Hoyle state did not exist, only very little carbon or other higher elements such as oxygen, nitrogen and iron could have formed. Without this type of carbon nucleus, life probably also would not have been possible.

The search for the "slave transmitter"

The Hoyle state had been verified by experiments as early as 1954, but calculating it always failed. For this form of carbon consists of only three, very loosely linked helium nuclei - more of a cloudy diffuse carbon nucleus. And it does not occur individually, only together with other forms of carbon. "This is as if you wanted to analyze a radio signal whose main transmitter and several slave transmitters are interfering with each other," explained Prof. Dr. Evgeny Epelbaum (Institute of Theoretical Physics II at Ruhr-Universität Bochum). The main transmitter is the stable carbon nucleus from which humans - among others - are made. "But we are interested in one of the unstable, energy-rich carbon nuclei; so we have to separate the weaker radio transmitter somehow from the dominant signal by means of a noise filter."

What made this possible was a new, improved calculating approach the researchers used that allowed calculating the forces between several nuclear particles more precisely than ever. And in JUGENE, the supercomputer at Forschungszentrum Jülich, a suitable tool was found. It took JUGENE almost a week of calculating. The results matched the experimental data so well that the researchers can be certain that they have indeed calculated the Hoyle state.

More about how the Universe came into existence

"Now we can analyze this exciting and essential form of the carbon nucleus in every detail," explained Prof. Meißner. "We will determine how big it is, and what its structure is. And it also means that we can now take a very close look at the entire chain of how elements are formed."

In future, this may even allow answering philosophical questions using science. For decades, the Hoyle state was a prime example for the theory that natural constants must have precisely their experimentally determined values, and not any different ones, since otherwise we would not be here to observe the Universe (the anthropic principle). "For the Hoyle state this means that it must have exactly the amount of energy it has, or else, we would not exist," said Prof. Meißner. "Now we can calculate whether - in a changed world with other parameters - the Hoyle state would indeed have a different energy when comparing the mass of three helium nuclei." If this is so, this would confirm the anthropic principle.

More information: E. Epelbaum, H. Krebs, D. Lee, Ulf-G. Meißner, Ab initio calculation of the

Hoyle state, *Physical Review Letters*, 2011. DOI: 10.1103/PhysRevLett.106.192501

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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