Physicists explain the long, useful lifetime of carbon-14

May 26 2011

Iowa State University physicists, left to right, Pieter Maris and James Vary have used supercomputing power to solve the puzzle of the long, slow decay of carbon-14. That long half-life makes carbon-14 a useful tool to determine the ages of skeletons and other artifacts. Credit: Photo by Bob Elbert/Iowa State University

The long, slow decay of carbon-14 allows archaeologists to accurately date the relics of history back to 60,000 years.

And while the carbon dating technique is well known and understood (the ratio of carbon-14 to other carbon isotopes is measured to determine the age of objects containing the remnants of any living thing), the reason for carbon-14's slow decay has not been understood. Why, exactly, does carbon-14 have a half-life of nearly 6,000 years while other light atomic nuclei have half-lives of minutes or seconds? (Half-life is the time it takes for the nuclei in a sample to decay to half the original amount.)

"This has been a very significant puzzle to nuclear physicists for several decades," said James Vary, an Iowa State University professor of physics and astronomy. "And the underlying reason turned out to be a fairly exotic one."

The reason involves the strong three-nucleon forces (a nucleon is either a neutron or a proton) within each carbon-14 nucleus. It's all about the simultaneous interactions among any three nucleons and the resulting influence on the decay of carbon-14. And it's no easy task to simulate those interactions.

In this case, it took about 30 million processor-hours on the Jaguar supercomputer at Oak Ridge National Laboratory in Tennessee. Jaguar has a peak performance of 2.3 quadrillion calculations per second, a speed that topped the list of the world's top 500 supercomputers when the carbon-14 simulations were run.

The research project's findings were recently published online by the journal *Physical Review Letters*.

Vary and Pieter Maris, an Iowa State research staff scientist in physics and astronomy, are the lead authors of the paper. Collaborating on the paper are Petr Navratil of TRIUMF (Canada's National Laboratory for Particle and Nuclear Physics in Vancouver) and the Lawrence Livermore National Laboratory in California; Erich Ormand of Lawrence Livermore National Lab; plus Hai Ah Nam and David Dean of Oak Ridge National Lab. The research was supported by contracts and grants from the U.S. Department of Energy Office of Science.

Vary, in explaining the findings, likes to remind people that two subatomic particles with different charges will attract each other. Particles with the same charges repel each other. Well, what happens when there are three particles interacting that's different from the simple addition of their interactions as pairs?

The strong three-nucleon interactions are complicated, but it turns out a lot happens to extend the decay of carbon 14 atoms.

"The whole story doesn't come together until you include the three-particle forces," said Vary. "The elusive three-nucleon forces contribute in a major way to this fact of life that carbon-14 lives so long."

Maris said the three-particle forces work together to cancel the effects of the pairwise forces governing the decay of carbon-14. As a result, the carbon-14 half-life is extended by many orders of magnitude. And that's why carbon-14 is a very useful tool for determining the age of objects.

To get that answer, Maris said researchers needed a billion-by-billion matrix and a computer capable of handling its 30 trillion non-zero elements. They also needed to develop a computer code capable of simulating the entire carbon-14 nucleus, including the roles of the three-nucleon forces. Furthermore, they needed to perform the corresponding simulations for nitrogen-14, the daughter nucleus of the carbon-14 decay. And, they needed to figure out how the computer code could be scaled up for use on the Jaguar petascale supercomputer.

"It was six months of work pressed into three months of time," Maris said.

But it was enough for the nuclear physicists to explain the long half-life of carbon-14. And now they say there are more puzzles to solve:

"Everybody now knows about these three-nucleon forces," Vary said. "But what about four-nucleon forces? This does open the door for more study."

Provided by Iowa State University