Researchers recalculate age of Solar System

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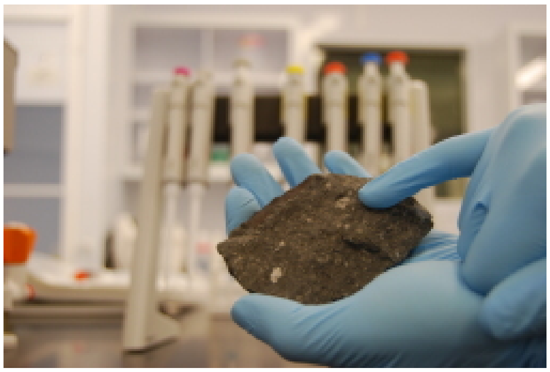

Brennecka points to a calcium-aluminum-rich inclusion (CAI) in a meteorite. The absolute ages of the CAIs, determined through Pb-Pb dating, are generally considered to date the origin of the Solar System. Credit: Celeste Riley.

(PhysOrg.com) -- Lead-lead (Pb-Pb) dating is among the most widely used radiometric dating techniques to determine the age of really old things, such as the age of the Earth or the Solar System. However, recent advances in instrumentation now allow scientists to make more precise measurements that promise to revolutionize the way the ages of some samples are calculated with this technique.

Radiometric dating can be used to determine the age of a wide range of natural and human-made materials. The comparison between the observed abundance of a naturally occurring radioactive isotope, such as uranium (U), and its decay products can be used to determine the age of a material, using known decay rates. The Pb-Pb dating technique has been used for decades under the assumption that the ratio of the 238U and 235U isotopes, both of which decay to different isotopes of Pb, is constant in the Solar System. This assumed value is built into the Pb-Pb age equation.

According to research published online in the Dec. 31 issue of Science Express and in the Jan. 22 issue of *Science* magazine by Greg Brennecka, a graduate student in the School of Earth and Space Exploration (SESE) at Arizona State University (ASU), the $^{238}U/^{235}U$ ratio can no longer be considered a constant in meteoritic material. Any deviation from this assumed value causes miscalculation in the determined Pb-Pb age of a sample, meaning that the age of the Solar System could be miscalculated by as much as several million years. Although this is a small fraction of the 4.57 billion year age of the Solar System, it is significant since some of the most important events that shaped the Solar System occurred within the first 10 million years of its formation.

Brennecka and colleagues at ASU and at the University of Frankfurt, Germany, measured the $^{238}U/^{235}U$ ratio in the earliest solids in the Solar System, calcium-aluminum-rich inclusions (CAIs). CAIs were the first solids to condense from the cooling protoplanetary disk during the birth of the Solar System. The absolute ages of the CAIs, determined through Pb-Pb dating, are generally considered to date the origin of the Solar System. The high-precision data they obtained from CAIs of the Allende meteorite showed that the $^{238}U/^{235}U$ ratio is not the same in all CAIs.

"This variation implies substantial uncertainties in the ages previously determined by Pb-Pb dating of CAIs," explains Brennecka. "This will likely make U isotope measurements part of the procedure for Pb-Pb dating, as the $^{238}U/^{235}U$ ratio can no longer be assumed to be invariant."

Brennecka began to think about the idea that the U isotope ratio might not be constant in meteoritic material after learning about work done by Professor Stefan Weyer of the Goethe University of Frankfurt during a sabbatical visit to ASU the previous year. Weyer spent a semester at ASU developing a technique to measure natural variation of U isotopes in Earth and planetary materials, working in the state-of-the-art laboratories of Ariel Anbar, a professor in SESE and ASU's College of Liberal Arts and Science's Department of Chemistry & Biochemistry, and in the W. M. Keck Foundation Laboratory for Environmental Biogeochemistry. That work revealed measurable differences in $^{238}U/^{235}U$ in different environments on Earth, when everyone thought the ratio was invariant in everything on Earth and our Solar System.

At this time, Brennecka was taking a class on meteorites and the origin of the Solar System from Meenakshi Wadhwa, a professor in the School of Earth and Space Exploration and director of the ASU Center for Meteorite Studies. For a class assignment, Brennecka developed a research proposal centered on the implications of variable U isotopes in early Solar System materials. Anbar and Wadhwa encouraged him to take the proposal from the classroom to the laboratory.

"This project is a prime example of what's possible as a result of the unusual culture of collaboration and cross-fertilization that exists in SESE, and at ASU in general," says Anbar. "It is also a direct result of ASU's investments in world-class laboratory facilities for Earth and planetary sciences. Those facilities were critical for Greg's measurements, and also sparked the collaboration with Stefan Weyer's group that started us down this research path."

Brennecka worked with Anbar and Wadhwa to refine the procedures at ASU to be able to measure $^{238}U/^{235}U$ in the extremely small CAIs, using Wadhwa's lab and instruments in the ASU Center for Meteorite Studies. Eleven of the thirteen CAIs were from the ASU Center for Meteorite Studies collection; the other two were from the Senckenberg Museum collection in Frankfurt. The project was supported by the National Aeronautics and Space Administration (NASA), including the NASA

Origins of Solar Systems Program, and the NASA Astrobiology Institute (NAI). ASU is home to one of 14 research teams from across the country that comprise the NAI which explores the origin, evolution, distribution, and future of life on Earth and in the universe.

"We started with CAIs because the Pb-Pb age of those materials is considered the start of the Solar System, so that is one of the most important dates for the cosmochemistry community, and it should be as accurate as possible," explains Brennecka. "Because this was a very new area of research and to ensure accurate results, we talked with Stefan, who was then back in Frankfurt, to set up a collaborative effort for laboratory comparison on the results. We shared samples and standards and independently ran tests to see if we got the same answer, which we did."

The U isotope ratios in all but two CAIs differed significantly from the standard "assumed" value. One of the possible mechanisms that could have produced these U isotope variations in meteorites is the decay of extant ^{247}Cm to ^{235}U. ^{247}Cm is created during only certain types of supernovae and has a very short half-life (15.6 million years) compared to the age of the Solar System, so all of the ^{247}Cm that was present originally has since completely decayed away. Brennecka and colleagues performed additional tests to determine if this was the cause of the U isotope variation.

If a correlation existed between the ^{238}U/^{235}U values and the original Cm/U in the CAIs, it would provide evidence that ^{247}Cm was the reason for the 238U/235U variations. Since ^{235}U is from the decay of ^{247}Cm, higher Cm/U ratios mean there is relatively more ^{235}U produced from ^{247}Cm decay. As Cm has no long-lived stable isotope, the initial Cm/U ratio of a sample cannot be directly determined, so geochemical proxies were used. The correlation of these proxies, or elements that behave like Cm, with U isotope ratios in the CAIs provided strong evidence for the presence of extant ^{247}Cm in the early Solar System. The $^{238}U/^{235}U$ ratios Brennecka obtained from the Allende meteorite were used to quantify the amount of ^{247}Cm present in the early Solar System.

"Cosmochemists have searched for evidence for live ^{247}Cm in the early Solar System for decades, and this is the first time that its presence has been demonstrated definitively. This work not only impacts precise and accurate dating of the earliest events to occur in our Solar System, but it also has broader implications for the environment and conditions in which our Solar System was born," explains Wadhwa.

"It is possible that in the future we will be able to use the ^{247}Cm-^{235}U system as a short-lived chronometer," says Brennecka. "But most importantly in the short term, this will help improve the accuracy of Pb-Pb dating."

Provided by Arizona State University

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