Reconstructing the solar system's original architecture

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LLNL researchers have found that the current locations of many planetary bodies in the solar system are not where they originally formed. Credit: NASA

As the solar system was developing, the giant planets (Jupiter and Saturn) formed very early, and as they grew, they migrated both closer to and further away from the sun to stay in gravitationally stable orbits.

The gravitational effect of these massive objects caused immense reshuffling of other planetary bodies that were forming at the time, meaning that the current locations of many planetary bodies in our solar system are not where they originally formed.

Lawrence Livermore National Laboratory (LLNL) scientists set out to reconstruct these original formation locations by studying the isotopic compositions of different groups of meteorites that all derived from the asteroid belt (between Mars and Jupiter). The asteroid belt is the source of almost all of Earth's meteorites, but the material that makes up the asteroid belt formed from sweeping of materials all over the solar system. The research appears in *Earth and Planetary Science Letters*.

"The significant reorganization of the early solar system due to giant planet migration has hampered our understanding of where planetary bodies formed," said Jan Render, LLNL postdoc and lead author of the paper. "And by looking at the makeup of meteorites from the asteroid belt, we were able to determine that their parent bodies must have accreted from materials from very different locations in the early solar system."

Even though the asteroid belt is only a relatively narrow band of the solar system, it contains an impressively diverse collection of materials. For example, multiple spectroscopically distinct asteroid families have been identified within the main belt, indicating vastly different chemical compositions. In addition, meteorites are known to derive from roughly 100 distinct parent bodies in the belt, with diverse chemical and isotopic signatures.

Tracing the source material of planetary bodies requires signatures that are established during planetary body accretion. Isotopic anomalies of nucleosynthetic origin represent powerful tools because these signatures fingerprint the actual building material from which these planetary bodies accreted.

"If we want to know what the solar system looked like at inception, we need a tool to reconstruct this primordial structure," said LLNL cosmochemist Greg Brennecka, co-author of the paper. "We've found a way to use isotopic signatures in meteorites to reconstruct what the solar system looked like when it was formed."

The team took samples of basaltic achondrites (stony meteorites similar to terrestrial basalts) to measure their nucleosynthetic isotope signatures in the elements neodymium (Nd) and zirconium (Zr). Their work showed that these elements are characterized by relative deficits in isotopes hosted by a certain type of presolar material. This data is well correlated with nucleosynthetic signatures observed in other elements, demonstrating that this presolar material was distributed as a gradient throughout the early solar system.

"By comparing these isotopic signatures with other proxies for solar system reconstruction, this links the original formation location of planetary bodies to their current positions," Render said. "These measurements help us create a reconstruction of the primordial solar system by 'cosmolocating' the accretion orbits of meteoritic parent bodies."

More information: Jan Render et al. Isotopic signatures as tools to reconstruct the primordial architecture of the Solar System, *Earth and Planetary Science Letters* (2020). DOI: 10.1016/j.epsl.2020.116705

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