# Dating the solar system's giant planet orbital instability using enstatite meteorites

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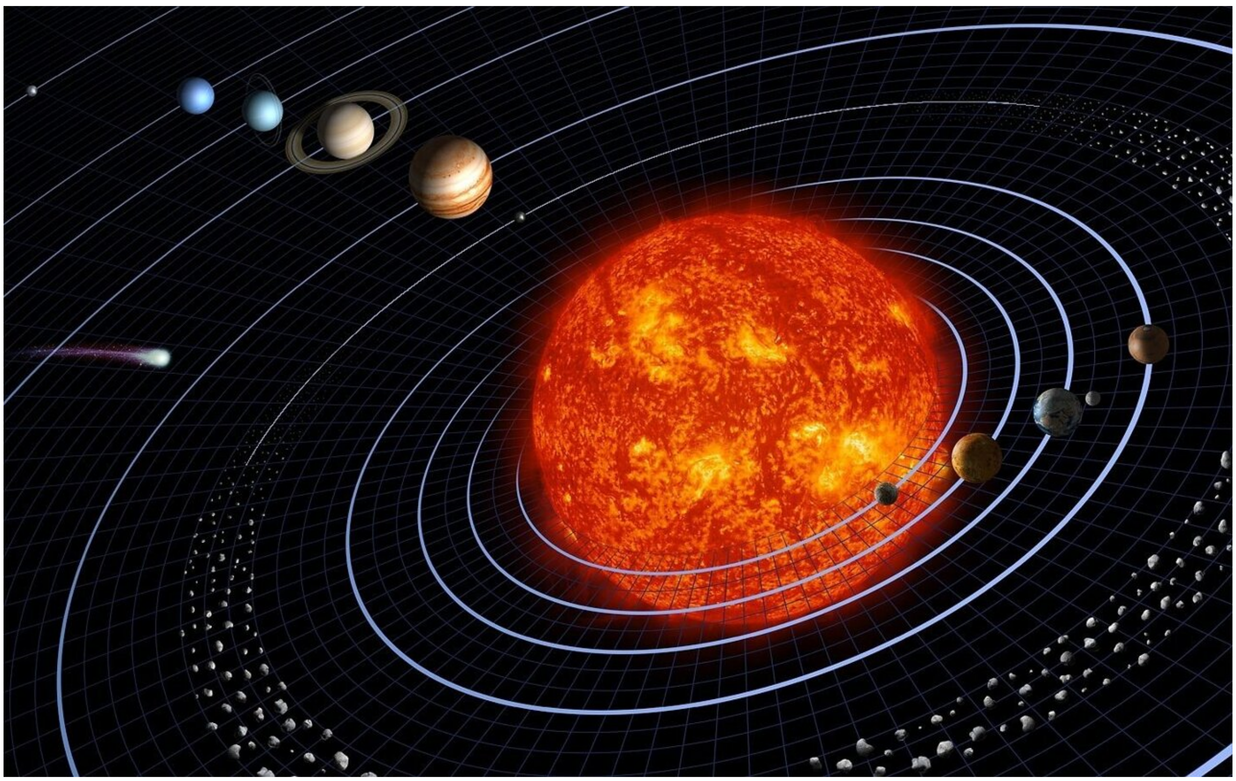

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Evidence from the fragments of a destroyed asteroid suggests that the shift in the positions of the giant planets in our solar system billions of years ago happened between 60–100 million years after the solar system's formation and could have been key to the formation of our moon.

Space scientists led by the University of Leicester have combined evidence from simulations, observations and analysis of meteorites to recreate the orbital instability caused as the giant planets of our solar system moved into their current locations, known for 20 years as the Nice model.

The findings are published in the journal *Science* and presented at the European Geological Union General Assembly in Vienna.

At the beginning of the solar system, the giant planets—Jupiter, Saturn, Uranus, and Neptune—had more circular and more compact orbits than they do today. Previous research has established that orbital instability in the solar system changed that orbital configuration and caused smaller planetesimals to be dispersed. Many of these collided with the inner terrestrial planets in what scientists have termed the Late Heavy Bombardment.

Lead author Dr. Chrysa Avdellidou from the University of Leicester School of Physics and Astronomy said, "The question is, when did it happen? The orbits of these planets destabilized due to some dynamical processes and then took their final positions that we see today. Each timing has a different implication, and it has been a great matter of debate in the community."

"What we have tried to do with this work is to not only do a pure dynamical study but combine different types of studies, linking observations, dynamical simulations, and studies of meteorites."

They focused on a type of meteorite known as enstatite chondrites, which have a very similar composition to Earth and very similar isotopic ratios, which means they were formed in our neighborhood. By making spectroscopic observations using ground-based telescopes, they linked those meteorites to their source: a family of fragments in the asteroid belt known as Athor.

This suggests that Athor was originally much larger and formed closer to the sun and that it suffered a collision that reduced its size out of the asteroid belt.

To explain how Athor ended up in the asteroid belt, the scientists tested various scenarios using dynamical simulations, concluding that the most likely explanation was the gravitational instability that shifted the giant planets to their current orbits. Analysis of the meteorites showed that this occurred no earlier than 60 million years after the solar system began to form.

Previous evidence from asteroids in Jupiter's orbit has also put constraints on how late this event occurred, with scientists concluding that the gravitational instability must have occurred between 60 and 100 million years after the birth of the solar system, 4.56 billion years ago.

Previous evidence has shown that Earth's moon was formed during this period, with one hypothesis being that a planetesimal known as Theia collided with Earth, and debris from that collision formed the moon.

Timing of the orbital instability is important as it determines when some of the familiar features of our solar system would develop—and may even have had an impact on the habitability of our planet.

Dr. Avdellidou added, "It's like you have a puzzle, you understand that something should have happened, and you try to put events in the correct order to make the picture that you see today. The novelty with the study is that we are not only doing pure dynamical simulations, or only experiments, or only telescopic observations."

"There were once five inner planets in our solar system and not four, so that could have implications for other things, like how we form habitable planets. Questions like, when exactly did objects come delivering volatile organics to our planet to Earth and Mars?"

Marco Delbo, co-author of the study and Director of Research at Nice Observatory in France, said, "The timing is very important because a lot of planetesimals populated our solar system at the beginning. And the instability clears them, so if that happens 10 million years after the beginning of the solar system, you clear the planetesimals immediately, whereas if you do it after 60 million years, you have more time to bring materials to Earth and Mars."

**More information:** Chrysa Avdellidou et al, Dating the Solar System's giant planet orbital instability using enstatite meteorites, *Science* (2024). DOI: 10.1126/science.adg8092

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