Improved simulation methods help scientists bolster theories of Moon's formation

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New simulation methods and higher-performance supercomputers lead to alternative explanations of how the Moon might have been formed. Credit: Flickr

(Phys.org)—There are still unanswered questions regarding how the Moon was formed. Improved simulation methods and higher-performance supercomputers have now paved the way for an alternative development model that could close gaps in our knowledge. This model allows the researchers more scope in the basic assumptions they make.

In the years after the Apollo mission, the three models on the formation of the Moon that were widely accepted up until that time collapsed like a house of cards.

The research work carried out on rock samples from the Moon showed that it did not split off from the Earth around 4.5 billion years ago, nor does it shine down from the sky because it became trapped in the Earth's gravitational pull, or because it formed together with the Earth from the pre-solar nebula. Suddenly a whole new model was needed to explain the Moon's formation.

Saved by the "giant impact" model

The American planetary scientist William Hartmann was the first to provide a plausible alternative to the models that had become outdated. In 1975, he suggested that the Moon was formed from the debris flung into the Earth's orbit by a giant collision between a protoplanet and the Earth.

This "giant impact" hypothesis is widely accepted today. The hypothesis states that a body called Theia that was approximately the size of Mars collided with the Earth and gave rise to the formation of the Moon.

But this hypothesis also involves discrepancies that still have not been possible to fully resolve to date. Scientists from ETH Zurich and the University of Bern have now proposed a refinement of that hypothesis, whereby a hit-and-run collision with Theia could explain the formation of the Moon. According to this new hypothesis, large volumes of debris from Theia could have escaped the gravitational pull of the Earth after the collision between Theia and the Earth.

"This way, a considerably higher portion of the Earth's mantle could have contributed to the formation of the Moon than in the conventional theory", says Matthias Meier, co-author of the study, which is part of his doctoral thesis at ETH Zurich.

Moon and the Earth too similar

There are lots of tough nuts to crack in the models on the formation of the Moon, for example the fact that the rocks from the surface of the Earth and the Moon have the same isotopic composition. The Moon has a significantly lower density, and the total angular momentum of the Earth-Moon system is high compared to other planets.

The models developed thus far assume that the Earth and Theia lost just a small amount of mass upon collision and that the Earth-Moon system lost no more than ten percent of its original angular momentum. This assumption has heavily restricted the parameters of the models and requires the Moon to be made up of unequal parts comprising 80% protoplanet and 20% proto-Earth.

Various studies over the past ten years (see also ETH Life Online from 20 December 2007) have shown, however, that the chemical composition of the rock on the Moon and on the Earth is much too similar for this theory to be accurate. "If the Moon is made up of 80% Theia material but the Earth only contains 10% of that material, as would have to be the case for the giant impact theory to be correct, then Theia would have to have had almost the same isotopic composition as the Earth�, explains Matthias Meier. He goes on to explain that this is unlikely, as meteorites and other celestial bodies have isotopic compositions that are quite different from those of the Earth.

One possible explanation for the similarity is that the collision gave rise to the development of a gigantic magma disk in the Earth's orbit, which allowed the chemical elements to exchange between the Moon and the Earth.

More Earth material necessary

The researchers have now come up with an alternative model for the formation of the Moon by means of a total of 60 simulations with three different colliding classes of bodies comprising different percentages of silicate and iron in terms of their weight. Furthermore, some of the protoplanets used in the simulation were made up of 50% water-ice.

They were able to use the models to show that, with a steeper angle of impact and a higher speed of Theia, much more material is ejected from the Earth� mantle. At the same time the loss of mass is also greater, however, chiefly because parts of Theia colliding with the Earth are flung away. What remains is a disk of very hot rock fragments, a significant portion of which stems from the Earth, from which the Moon was later formed.

The simulations came closest to the actual Earth-Moon system with Theia having a speed of approximately 15 kilometres per second and a steep angle of impact of between 30 and 35 degrees upon collision. However, the researchers were unable to find a perfect match for the Earth-Moon system. Consequently they concede that further simulations will be necessary in order to resolve the debate on the formation of the Moon.

However, they tell us that their new approach, which allows more scope in the choice of parameters, provides an alternative scenario for the conventional giant impact model. For example, according to the researchers the angular momentum of the Earth-Moon system no longer has to be so heavily restricted. As some of the angular momentum is carried away by the escaping mass, the combined momentum of the two bodies could thus have been much higher before the collision.

Theia fragments permitted

The model could also turn out to be helpful for the hypothesis that the chemical elements of the Moon and the Earth were exchanged in the hot magma disk that formed after the collision of the celestial bodies in the Earth's orbit.

"This means that the model includes the possibility of the Moon also comprising material from the protoplanet", says Rainer Wieler, Professor at the Institute of Geochemistry and Petrology at ETH Zurich and co-author of the study.

"The idea for the study came from Matthias Meier. He asked what would have happened if a protoplanet made of rock, and covered by a thick layer of ice, had collided with the Earth at high speed", emphasizes Wieler. These questions led to collaboration with Willy Benz, a professor at the University of Bern, and his doctoral student at the time, Andreas Reufer.

Benz had wanted to carry out similar simulations several years ago, but had abandoned these again due to insufficient resolution of the models. Better methods and higher-performance computers ultimately helped to develop the new hypothesis on the formation of the Moon.

More information: Reufer A, Meier MMM, Benz W & Wieler R: A hit-and-run giant impact scenario, *Icarus*, online publication. DOI:10.1016/j.icarus.2012.07.021.

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