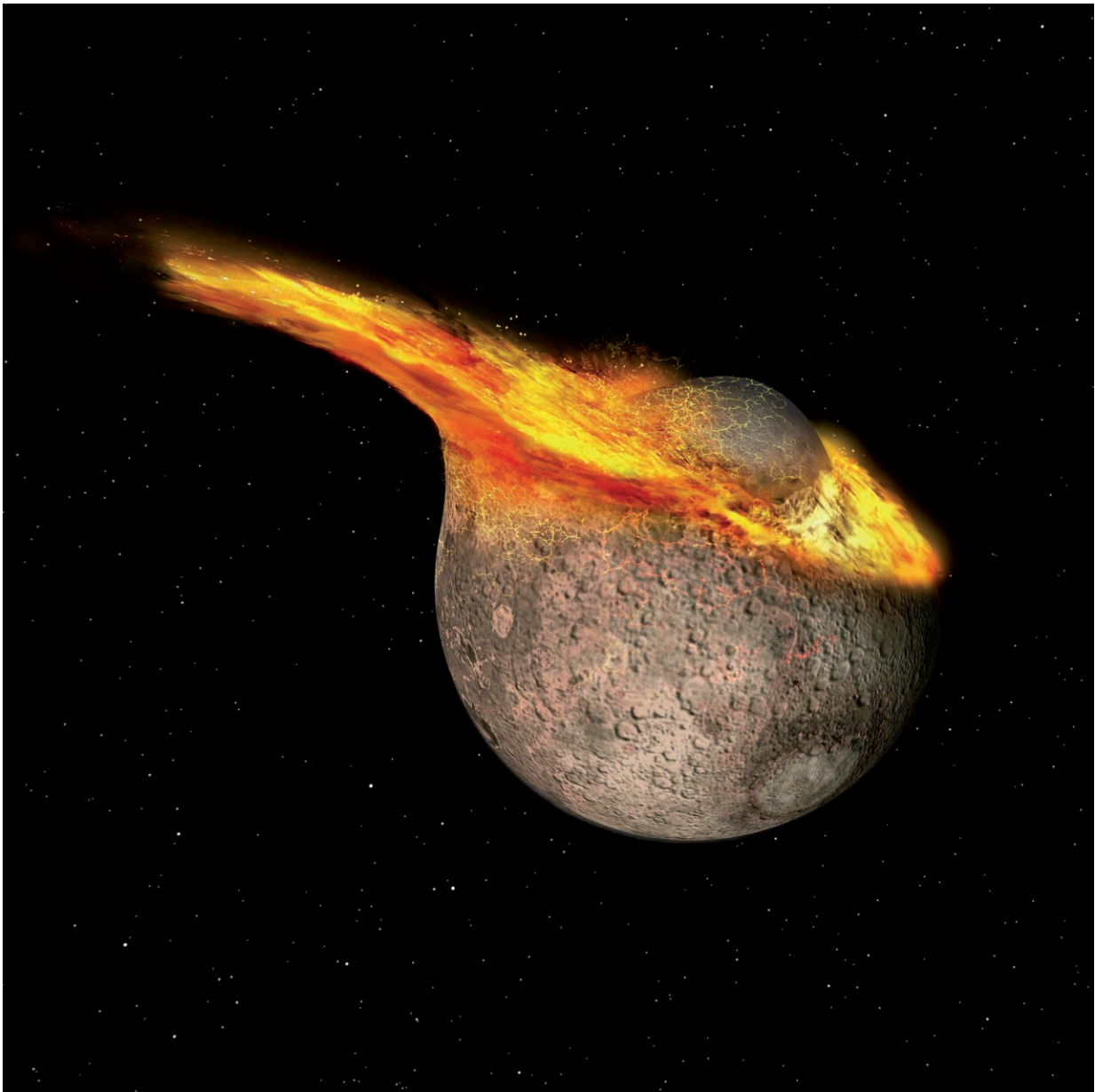


# Researchers find younger age for Earth's moon

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The moon is born. Credit: Ron Miller

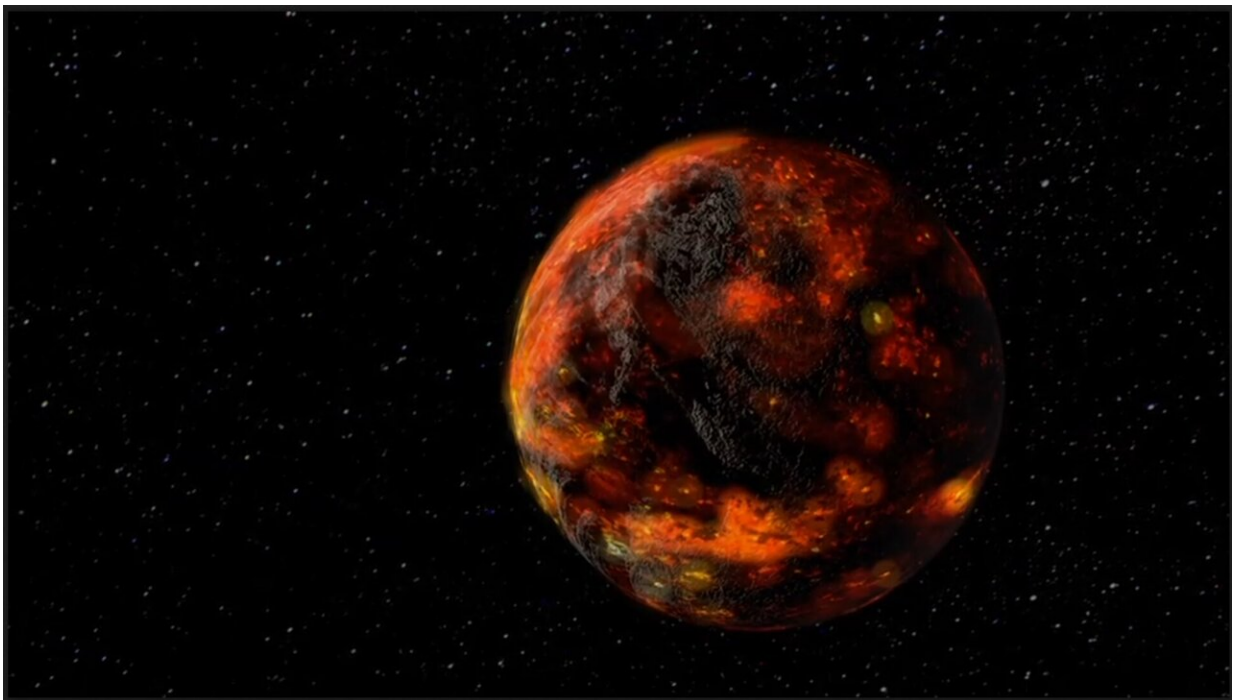
The moon formed a little later than previously assumed. When a Mars-sized protoplanet was destroyed in a collision with the young Earth, a new body was created from the debris ejected during this collision, which became the moon. Planetary geophysicists at the German Aerospace Center (Deutsches Zentrum für Luft- und Raumfahrt; DLR), led by Maxime Maurice, together with researchers at the University of Münster, have used a new numerical model to reconstruct the time at which the event occurred—4.425 billion years ago. The previous assumptions about the formation of the moon were based on an age of 4.51 billion years—that, is 85 million years earlier than the new calculations reveal. The scientists have reported their findings in *Science Advances*.

Four and a half billion years ago, the solar system was still chaotic. Earth was still growing to its present size, collecting matter in the form of what are referred to as planetesimals. These had previously formed in the disc of dust and gas orbiting the early sun. The young Earth consolidated, becoming ever hotter inside. Increasingly, large parts of the rocky mantle melted and formed a magma ocean. It is at this time that Earth gained the natural satellite that continues to orbit around it to this day. A massive cosmic collision between Earth and a protoplanet ejected rock from the young Earth. Eventually, this debris agglomerated to form a new planetary body—the moon.

In principle, most scientists agree about how the moon formed, but not about the details of the process, and especially not about the time at which it occurred. "The results of our latest modeling suggest that the young Earth was hit by a protoplanet some 140 million years after the birth of the solar system 4.567 billion years ago," says Maxime Maurice,

summarizing the team's investigations. "According to our calculations, this happened 4.425 billion years ago—with an uncertainty of 25 million years—and the moon was born."

At that time, Earth had just developed into a planet. During this development, the heavy metallic components sank to its center and formed a core of iron and nickel, which was surrounded by a thick mantle of silicate rocks. The mantle rocks became increasingly hot due to the process of accretion and the decay of radioactive elements. This allowed the separation of metals and silicates to take place in Earth's interior within a few tens of millions of years.



Magma ocean and first rocky crust on the moon. Credit: NASA/Goddard Space Flight Center

## **A planetary bullseye caused the formation of the moon**

At this stage, Earth was hit by Theia, a protoplanet that was perhaps the size of Mars. Theia was one of the Titans in Greek mythology, and the mother of the moon goddess Selene. In the early days of the solar system, there would have been many bodies of this kind. Some were ejected from the solar system, while others were destroyed by collisions with other bodies. Theia, however, hit Earth and caused the ejection of such a large amount of material from the planet's mantle that the moon was able to form from it. During this violent impact, a several-thousand-kilometer-deep magma ocean formed. Today, no traces of Theia remain following this collision.

Reconstructing how the formation of the moon was triggered by this event requires a great deal of imagination and creativity. The collision of the two bodies, with its enormous energy, also vaporized a large amount of rock from Earth's early mantle. This was ejected and collected in a ring of dust around Earth before it reassembled there to form rock. "From this, the moon was formed in a short time, probably in just a few thousand years," explains Doris Breuer, Head of the Planetary Physics Department at the DLR Institute of Planetary Research and a co-author of the study.

## **The oldest moon rock is not old enough**

Scientists largely agree about the history of the moon's formation. However, they have not been able to date it exactly, as none of the moon rocks brought to Earth by the astronauts of the six Apollo missions and the three Soviet Luna robotic missions directly record the age of Earth's natural satellite. Researchers from DLR and the University of Münster have determined when the moon was formed using a new, indirect method. "Our calculations show that this most likely happened at the very end of Earth's formation," says Sabrina Schwinger, another co-

author of the study, describing the chronological sequence of events.



One of the oldest moon rocks. Credit: NASA/JSC/AACO

It was not only Earth that had an ocean of magma in its early youth. Energy gained from accretion also led to the formation of a magma ocean on the moon. The moon melted almost completely and, similarly to Earth, was covered by a magma ocean over 1000 kilometers deep. This magma ocean quickly began to solidify and formed a crust of

floating, lightweight crystals at the surface—its 'interface' with the cold space. But under this insulating crust, which slowed down the further cooling and solidification of the magma ocean, the moon remained molten for a long time. Until now, scientists were unable to determine how long it took for the magma ocean to crystallize completely, which is why they could not conclude when the moon originally formed.

To calculate the lifetime of the moon's magma ocean, the scientists used a new computer model, which, for the first time, comprehensively considered the processes involved in the solidification of the magma. "The results from the model show that the moon's magma ocean was long-lived and took almost 200 million years to completely solidify into mantle rock," says Maxime Maurice. "The [time scale](#) is much longer than calculated in previous studies," adds DLR colleague Nicola Tosi, second author of the study and advisor of Maxime Maurice's Ph.D. thesis, which was the base for this condensed scientific report. "Older models gave a solidification period of only 35 million years."

## **Solidification models reveal the age of the moon and Earth**

To determine the age of the moon, the scientists had to go one step further. They calculated how the composition of the magnesium- and iron-rich silicate minerals that formed during the solidification of the magma ocean changed over time. The researchers discovered a drastic change in the composition of the remaining magma ocean as solidification progressed.

This finding is significant because it allowed the authors to link the formation of different types of rock on the moon to a certain stage in the evolution of its [magma](#) ocean. "By comparing the measured composition of the moon's rocks with the predicted composition of the [magma ocean](#)

from our model, we were able to trace the evolution of the [ocean](#) back to its starting point, the time at which the moon was formed," explains Sabrina Schwinger.

The results of the study show that the moon was formed  $4.425 \pm 0.025$  billion years ago. The moon's exact age is in remarkable agreement with an age previously determined for the formation of Earth's metallic core with the uranium-lead method, the point at which the formation of planet Earth was completed. "This is the first time that the age of the [moon](#) can be directly linked to an event that occurred at the very end of the Earth's formation, namely the formation of the core," says Thorsten Kleine from the Institute of Planetology at the University of Münster.

**More information:** M. Maurice et al. A long-lived magma ocean on a young moon, *Science Advances* (2020). [DOI: 10.1126/sciadv.aba8949](https://doi.org/10.1126/sciadv.aba8949)

Provided by DLR

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