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Press Release

Falling moons: When proto-Earth met its makers

German and Israeli supercomputers spend 100 weeks crunching astronomical numbers

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The Moon is Earth's only natural satellite. Its creation still raises many questions for astrophysical research – indeed, the Moon may not have been alone in the skies of primeval Earth. Recent studies have shown that there was once a number of smaller moons – known as moonlets – yet we do not know what became of them.

Working with Dr. Uri Malamud and Professor Hagai Perets of the Israeli Institute of Technology in Haifa and Christoph Burger of the University of Vienna, University of Tübingen's Christoph Schäfer has been investigating to find out what happened to Earth's moonlets. The researchers' complex simulations show that they could have fallen to Earth in collisions which changed the composition of Earth's mantle. Their study has been published in the latest edition of *Monthly Notices of the Royal Astronomical Society*.

According to the currently-accepted theory, the Moon was created some 4.5 billion years ago in a collision between the proto-Earth and another proto-planet the size of Mars. Astrophysicists call this proto-planet Theia. That led to the formation of a disc around the Earth, composed of material thrown out of both bodies by the collision. The material in the disc eventually conglomerated into the Moon we know today.

But the latest research shows that the Earth was subject to not one, but several such major collisions; and that smaller bodies hit the proto-Earth even more frequently. These processes led to the formation of several moonlets, which the researchers have assumed to have each been between one-sixth and half of the Moon's mass.

The astrophysicists have been investigating their fate. "There are two possibilities: The moonlets may have joined up under the force of gravity to form larger objects, or – the other possibility – they may have been

pulled down to the Earth," Christoph Schäfer explains. "Those are the two options we are looking at first and foremost."

To simulate the collisions of the moonlets with the Earth, the researchers used a computer program developed under Christoph Schäfer's direction at the Tübingen Institute of Astronomy and Astrophysics by Professor Wilhelm Kley's working group. The calculations themselves were conducted in the Tübingen BinAC computer cluster and the TAMNUN cluster in Israel. The Tübingen physicists' program used smooth particle hydrodynamics to model the processes, and graphics processing units to accelerate the highly complex computations. Christoph Burger of the Vienna University Institute for Astronomy and Astrophysics wrote the code for the complicated initial conditions for the simulations.

100 weeks of calculation time

The astrophysicists assumed a simplified model of the proto-Earth and a falling moonlet – in which both had an iron core and a silicate mantle. The core was set at one-third of the mass of each body. The group carried out more than 70 simulations of a moonlet colliding with the Earth, varying parameters such as the angle of impact, the size of the moonlet, and the rotational velocity of the Earth. "In total, the calculations took more than 100 weeks of computing time," says Uri Malamud.

In Haifa, Uri Malamud analyzed the results of the simulations. He determined which fragments of the bodies would have been able to escape from the system, which would have entered a captured orbit around the Earth, and which would remain after hitting the Earth. He also calculated the change in the Earth's rotation period caused by the collision. "Our results show that when a moonlet strikes the Earth, the incoming material is not homogeneously distributed. This kind of collision can therefore lead to asymmetries and inhomogenities in the composition of the Earth's mantle," says Uri Malamud. This collaborative research gives us a more complete picture of how the Moon was created and places it into the broader context of planetary formation in the solar system.

Publication:

Uri Malamud, Hagai B Perets, Christoph Schäfer, Christoph Burger: Moonfalls: collisions between the Earth and its past moons. *Monthly Notices of the Royal Astronomical Society*, https://doi.org/10.1093/mnras/sty1667

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