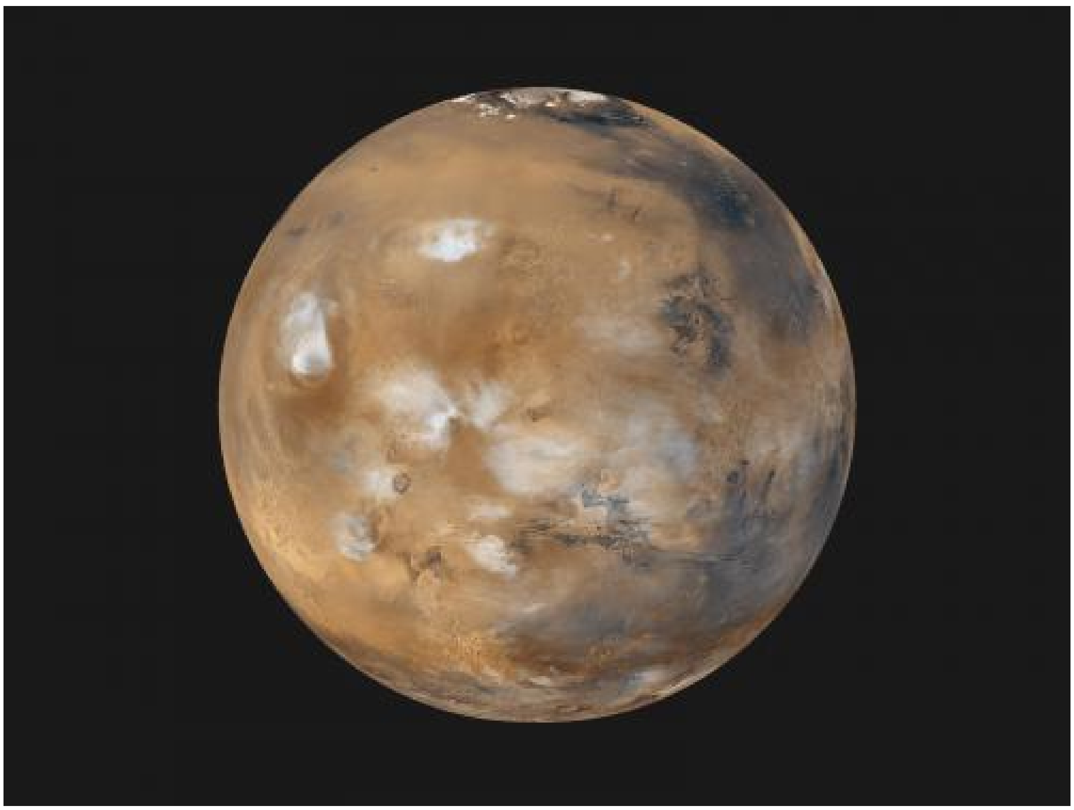
Solar system simulation reveals planetary mystery

September 8 2014, by Elizabeth Howell, Astrobio.net



A snapshot of weather patterns around Mars, including blue-white ice clouds that are visible above the Red Planet's Tharsis volcanoes. Credit: NASA/JPL-Caltech/MSSS

When we look at the Solar System, what clues show us how it formed? We can see pieces of its formation in asteroids, comets and other small bodies that cluster on the fringes of our neighborhood (and sometimes, fly closer to Earth.)

Are the orbits and sizes of the planets a natural byproduct of the formation, or are there features that happened because of rare events? Scientists are focused on answering these questions to better understand how the Earth formed, and what this means for Earth-like planets around other stars.

For example, a new set of simulations showed that Mars is a rare planet. It can happen, but only in certain situations—at least, if the parameters of the simulations are correct. Are these assumptions correct, or do other initial conditions need to be explored?

Finding the answers to these questions not only helps us understand where Mars comes from, but also our own planet. This is interesting to astrobiologists because the Red Planet has extensive evidence of past water.

Results from the Opportunity, Spirit and Curiosity rovers on the Martian surface came across features that form in the presence of water, such as mineralized iron oxide known as hematite, or"blueberries," because of its shape.

"The formation of Mars is a long-standing problem. Most previous studies like this have not been able to reproduce an object with Mars' mass," said Rebecca Fischer, a doctoral candidate in geophysical sciences at the University of Chicago, who led the research.

"It is possible to reproduce Mars, but it only happens 5 percent of the time. If you only ran four simulations, you wouldn't see it happen," she says.

Fischer's work, called "Dynamics of the terrestrial planets from a large number of N-body simulations," appeared in the journal Earth and Planetary Science Letters in April.

Jupiter and Saturn formed first

Fischer, who is a geologist by training, is interested in how the Earth came to be. Like other planets in the Solar System, the Earth arose from a cloud of gas and dust about 5 billion years ago. Over time, this cloud coalesced into chunks of material. The chunks collided and combined, eventually forming the planets and moons that we see today.

Predicting what conditions would form the eight planets of our solar system, however, is an extreme challenge. It requires modelling interactions over millions of years, and taking into account things such as how the orbits of the gas giant planets—specifically Jupiter and Saturn—affected how the Inner Solar System planets came to be.

A montage of the planets and some of the moons in our solar system, not to scale. Credit: NASA/JPL

Previous simulations of the Solar System formation were limited to just a few trials. Until this most recent work, the largest number of simulations, a total of 12, were described in a 2009 research paper called "Building the terrestrial planets: Constrained accretion in the inner Solar System." (The research was published in Icarus and is also available in preprint version on *Arxiv*.)

It is believed that Jupiter and Saturn formed before the Inner Solar System because they have so much gas inside of them. Similarly to the young Sun, these planets would have scooped up gas floating around in the vicinity. The gas would have only remained in the Solar System for a short time before the Sun's radiation blew it out of the Solar System, implying that the gas giant came together quickly. The gas giants were able to hold on to the gas because of their immense gravity.

For that reason, the model started with the assumption that Jupiter and Saturn existed when the Inner Solar System was still being formed. The researchers ran two sets of 50 simulations—one with Jupiter and Saturn close to the eccentric orbits that they have today, and one with Jupiter and Saturn in more circular orbits.

"We formed two to six Inner Solar System planets in our simulations, usually," Fischer says. "We do see something that looks like a Venus analog. Mercury is much harder. We see maybe one good analog out of all the simulations. That's something, that really no simulations are producing Mercury, so there's probably something wrong in the way of thinking about that."

Fischer acknowledged that the results may tell scientists that forming Mars and Mercury are low-probability events—possible, but rare. Or, the simulation may show scientists that the assumptions they have about the

Solar System need to be revisited. These are matters that will need to be addressed in future research, she said.

Building Earth

Besides forming the planets, the research also looked into how the presence of other planets affected how the Earth is formed. For example, our planet includes "volatiles" such as water on its surface. Is it possible that the mass of Mars changed how much water the Earth accreted? Fischer's simulations revealed that the amount of water on Earth appears to be independent of Mars.

What Fischer did notice, however, is that the orbits of Jupiter and Saturn greatly affected the amount of volatiles that were delivered to the Inner Solar System where Earth is. Water and some organic materials originate in the Outer Solar System, hence the reason that comets come from a hypothetical region called the Oort Cloud. This region has a large group of icy objects that are believed to be about 5,000 to 100,000 astronomical units (Earth-sun distances) from the Sun.

These icy objects remain far out in the Solar System, unless the orbits of the gas giants kick them closer to the Sun. A planet like Earth, which was in the process of accreting water, nitrogen and carbon (all important for life), likely depended a lot on the material that the gas giants delivered.

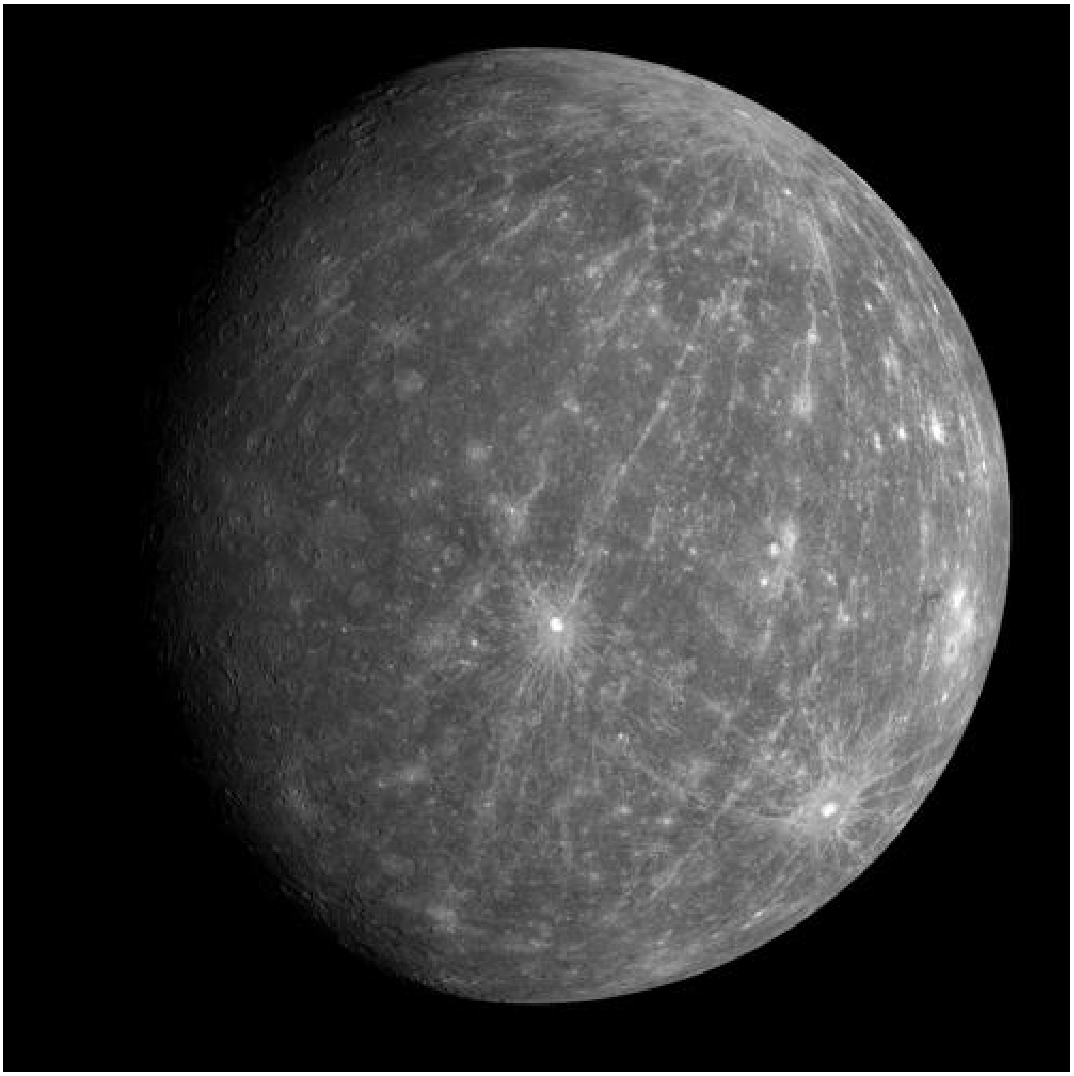
The orbits of Jupiter and Saturn may have affected how much water, nitrogen and carbon was delivered to Earth early in its history. Credit: NASA

Fischer found that the formerly circular orbits of early Jupiter and Saturn enabled the gas giants to deliver much of the volatiles into the Inner Solar System, a situation that would not be as possible with today's more eccentric orbits.

Models have come up with a few scenarios of Jupiter's and Saturn's orbits while the inner planets were forming. Perhaps their orbits crossed, or orbits moved towards the Sun and back out, but the reasons behind this are poorly understood.

How rare is our solar system?

Understanding how the Solar System is put together also has implications for life beyond Earth. If it is, indeed, rare for certain planets to form, this could also make it rarer for life to exist in the Universe. So far, Fischer said, scientists haven't been able to replicate the Solar System in models.



It is difficult to form Mercury in solar system simulations, suggesting that some of our assumptions about the small planet’s formation might be wrong, a new study suggests. Credit: NASA/Johns Hopkins University Applied Physics Laboratory/Carnegie Institution of Washington

"There's a lot of discussion over the philosophy of how to approach this, whether you look for the Solar System as the most likely outcome, or whether you should look for conditions that can produce the Solar System. Currently, there's no configuration that has been proposed that forms the Solar System most of the time."

For further studies, Fischer is interested in how the Solar System's formation could have affected the Earth's interior. For the planets coming together in the simulation, she will calculate how the incoming material is distributed between the Earth's core and mantle, the latter of which changes as a function of pressure and temperature in the Earth's core.

These simulations will help to pinpoint the temperature of Earth's core, which is unknown. The Earth's active surface, shaped by volcanic eruptions and earthquakes, is sometimes cited as a reason that life exists because it provides energy and change for organisms.

While the presence of Mars might be a rare situation for our solar system, it is a lucky one for astrobiologists. It is believed that studying Mars is good for understanding different conditions under which life could have happened, even if we're not sure life was ever there yet.

More information: Rebecca A. Fischer, Fred J. Ciesla, "Dynamics of the terrestrial planets from a large number of N-body simulations," *Earth and Planetary Science Letters*, Volume 392, 15 April 2014, Pages 28-38, ISSN 0012-821X, dx.doi.org/10.1016/j.epsl.2014.02.011.

"Building the Terrestrial Planets: Constrained Accretion in the Inner Solar System." Sean N. Raymond, David P. O'Brien, Alessandro Morbidelli, Nathan A. Kaib *arXiv*:0905.3750 [astro-ph.EP] arxiv.org/abs/0905.3750

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