
the moon
THE BEST EXPLANATION WE HAVE FOR THE ORIGIN OF THE MOON IS THAT A LONG, LONG TIME AGO A SMALL PLANETARY BODY HIT THE EARTH...
"...BLASTING BITS OF ROCK AND DEBRIS FROM THE COLLISION INTO ORBIT."
"THE DEBRIS EVENTUALLY CLUSTERED TOGETHER TO FORM OUR NEIGHBORING SATELLITE."
WHEN DID YOUR ANCESTORS BEGIN HOWLING AT IT—WHEN IT WAS STILL BITS OF DEBRIS?
NO.
THEY WAITED FOR A "FULL" MOON.
HA HA.

Genesis of the Moon

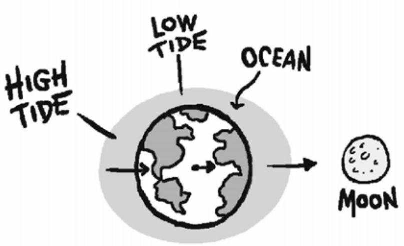
A Mini Big Bang Close to Earth

We are not alone in our solar system. There are quite a few neighbors, including other planets that orbit the sun as well. A little closer to the sun we have Venus and a little further away there is Mars, the most popular planet to be visited in the future. The movements of all these planets follow Kepler's laws (↗[1]). But next to all these planets we have a neighbor which is much closer and can easily be seen by eye: the moon.

It orbits our planet at about 1 km/s and takes about 27 days for a full orbit. Sometimes it is right in between us and the sun and causes solar eclipses. It has a radius of about 1700 km, which is roughly one quarter of Earth's radius. But its mass of about $7 \cdot 10^{22}$ kg is only about 1.2% of Earth's mass. Its density is hence much lower. The lower mass causes lower gravitational forces on the moon's surface: instead of with 9.8 m/s^2 (on Earth) you only get accelerated with 1.6 m/s^2, so only about 17% compared to the Earth. This would make you feel pretty light, if you were to take a walk on the moon. Still, the moon is heavy enough to let us feel its gravitational field down here on earth. On the side of Earth facing the moon, the water of our oceans gets attracted. On the opposite side, the water also feels a force away from the Earth's surface. This comes from the relative movement of the Earth and moon around their common center-of-mass. You can try the effect like Emmy and Maxwell pictured here: take a friend's hand and rotate. You feel that your fingers get dragged to the center (by your friend) and your hair, if it's long enough, sweeps to the outside. The same happens to the water on Earth. And if you imagine Earth rotating, every place on Earth will pass by the tidal wave twice a day and we can observe it as ebb and flow tide.

Our Moon – Somewhat Special

Our moon is not only special as it causes tidal waves, bright reflections from the sunlight which can guide you the way home on a dark night and maybe have some other special effects during a full moon. It is



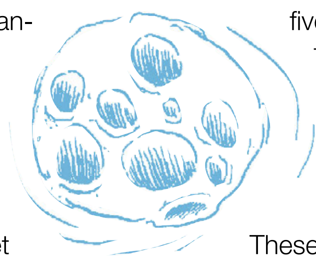
↗[1]: *"Kepler's Laws" on page 47*

B. Bahr, B. Lemmer, R. Piccolo, *Quirky Quarks*, DOI 10.1007/978-3-662-49509-4_16

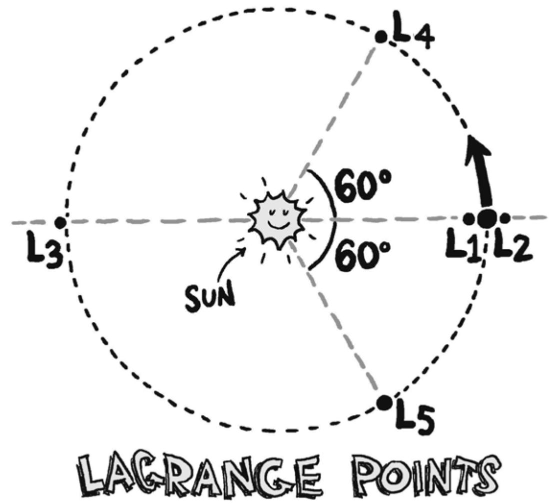
also unique in our solar system! Some planets have no moon at all. Others have neighbors that are not really worth being called moons, but are more like asteroids. Our moon is relatively large. It has a lower density than earth, but the elementary composition of its surface rocks is similar to the composition of our Earth. The question is: why is that? And this question is closely related to the question: what is the origin of our moon?

A Collision in Outer Space

Let us go back to the time when our solar system formed. It was, at the very beginning, nothing more than a cloud of dust. Compressed by its own gravity, this dust formed massive objects, starting with the sun and then also with farther large objects emerging from the remaining dust orbiting the sun. You can read more about the birth of our solar system and the formation of planets in a dedicated chapter (➚[2]).



Before our planet reached its final size, at about 90% of the mass that it has today, it was accompanied by another planet. It had the size of the planet Mars and shared an orbit with our Earth. That second planet, today also referred to as Theia, had a constant distance to our earth. There are only certain places where such a constant distance can be achieved. These points are called “Lagrange Points”.

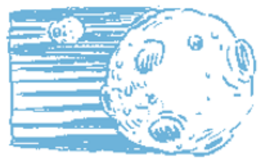


Think of the orbit of Earth around the sun. Let us assume that another, not too heavy object, wants to share that orbit. The problem is that the orbit is determined by the gravitational force between sun and earth. Whenever a third body comes into play, it does not only feel the attraction of the sun, but also the one from Earth. But there are exactly five points in the orbit where the gravitational forces are balanced and keep the orbit of the third body stable. These Lagrange points can be seen in the above illustration. Three of them are on the line between sun and earth.

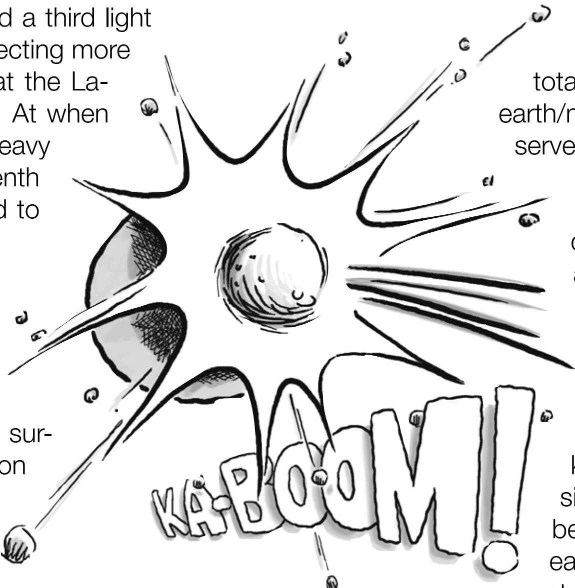
These Lagrange points are quite popular. Imagine that you want to place a satellite in a spot close to earth in order to observe the sun, such as the SOHO telescope. The best place is at the Lagrange point L_1! And if you are a satellite, and want to stay close to Earth but also want to observe the outer universe without being disturbed by our

➚[2]: *“Birth of the Solar System” on page 59*

sun: take L_2! This is what the WMAP satellite does as it collects information about the cosmic microwave background (↗[3]). And if you have a big secret and want to hide it, bring it to L_3. Nobody will ever see it from Earth, because it will always stay hidden by the sun.



Now, let us go back to our Earth prototype and its neighboring planet Theia. It was placed at L_4 or L_5 with constant distance to Earth. But this whole idea of the Lagrange points is only valid for two heavy objects (earth and sun) and a third light one. As Theia grew by collecting more and more dust, its place at the Lagrange point got unstable. At when it had become about as heavy as Mars – roughly one tenth of Earth's mass – it started to move towards the earth.



And then it happened: Earth and Theia collided. Theia was ripped apart and its remnants, together with parts of Earth, surrounded Earth. Theia's iron core, however, merged with Earth. The bits and pieces surrounding Earth formed our moon and our planet gained a little mass. This scenario of the origin of the moon is only one amongst several others. Other ideas are for example that the moon came from somewhere else, accidentally passing by Earth and then got caught by it. But the collision theory does a good job, in particular, it describes the similarity of the Earth's and moon's elementary composition.

Since the creation of the moon, its interplay with Earth has slightly changed. Each year, the distance between Earth and moon, measured via lasers (↗[4]), increases by about 4 cm. This is caused by the tides that we mentioned in the beginning. During the gravitational interplay between earth and moon the earth's rotation is slowed down, by the friction of water waves, rolling back and forth under the moon's influence. This means that its angular momentum is reduced. As the total angular momentum of the earth/moon system must be conserved (↗[5]) the moon's angular momentum is increasing. And due to that, the moon's distance to Earth increases as well. From its birth 4.5 billion years ago to now, the distance between the moon and Earth has increased from less than 100,000 km to 380,000 km, which is quite impressive. This means that at the beginning the tidal effects on earth must have been much stronger. Also, as Earth spins slower and slower, our days become longer. But as they increase by only 15 microseconds per year, the effect is nothing that we will realize during our lifetime. Except for one of these days where a leap second is added to our day, as it happened on the 30th of June in 2015.

↗[3]: *"The Cosmic Microwave Background" on page 105*
↗[4]: *"Lasers" on page 19*
↗[5]: *"Conservation Laws" on page 51*