How Galileo measured the height of the mountains on the moon

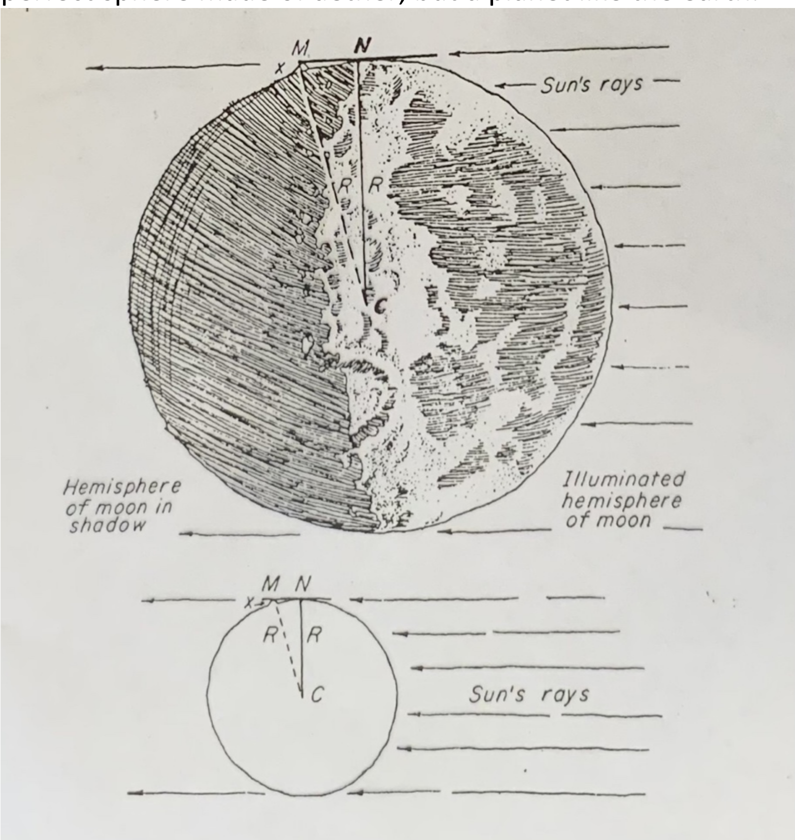
First of all, he knew that the diameter of the earth was about 7000 miles from past observations (the ancient Greeks, namely Eratosthenes in 230 BC figured out the circumferences of the earth with a little trigonometry, so the diameter was not difficult to deduce). Galileo also knew that the moon's diameter was about 2000 miles (a fact also discovered by the ancient Greeks, namely Aristarchus).

Secondly, if the moon's diameter was 2000 miles, its radius is 1000 miles (marked CN on the diagram)

Third, Galileo also knew the distance from the terminator (the boundary between the illuminated and non-illuminated part of the moon) to the mountain was approximately 1/20th the diameter of the moon, or about 100 miles. This is a distance MN on the diagram. So, if Galileo knows the radius (CN) and the distance MN, by the use of Pythagoras's theorem

$CN^2 + MN^2 = MC^2$
$1000^2 + 100^2 = 101000$ miles

If you take the square root of 101000 miles you get 1004 miles. The radius of the moon is 1000 miles, so the mountain must be four miles hight. This is fairly accurate, as the highest mountains on the moon are about 4.34 miles high. By showing that the moon had mountains like the earth, Galileo builds support for Copernicanism, as the moon is no perfect sphere made of aether, but a planet like the earth.



Name: **Date:**

PARALLAX EXERCISE[1]

The goal of this exercise is to introduce the student to the concept of parallax, which is a method used to measure distances here on Earth as well as in space.

EQUIPMENT: Ruler, Calculator

INTRODUCTION

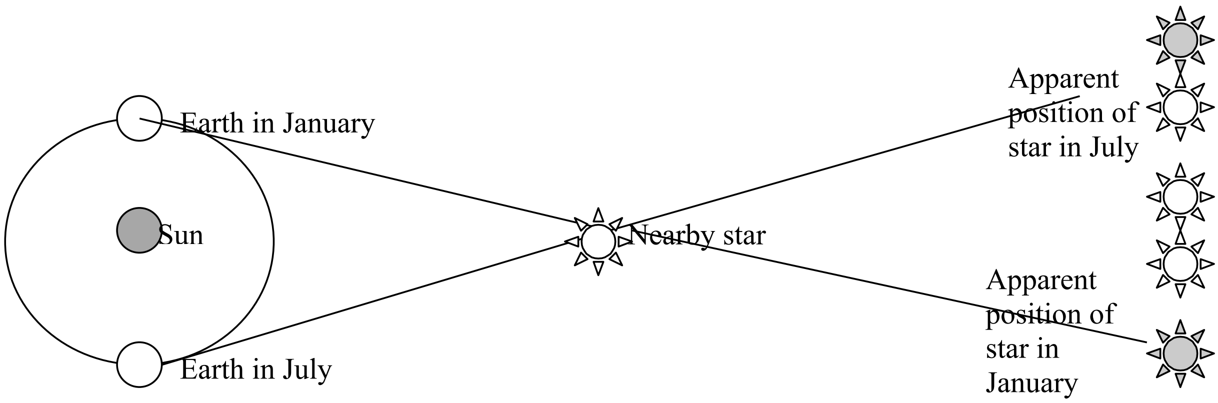
Compare the Sun to another star in the sky. They look completely different, and it was once believed that they *were* different types of objects. In fact, the Sun was once considered a planet! We now know the Sun is just another star, and the reason that the Sun appears different to us is that it is so much closer.

Determining distances to celestial objects is one of the most important and most difficult measurements in astronomy. The most direct method of distance measurement is *parallax*, the apparent shift in the position of an object due to the change in position of the observer. To see an example of this, hold a finger up at arm's length in front of you. Close one eye, and line up your finger with a distant object. Now look at your finger with the other eye – it will no longer be lined up with the distant object. As you close one eye and then the other, your finger appears to move back and forth. Your finger is not really moving, but the position from which you view your finger is changing. The shift you see is called *parallax*.

1. Place your finger at several positions from your face and repeat the experiment above. How does the parallax (the apparent shift of the position of your finger) change as your finger is moved closer to your face?

[1] Based on exercise developed at Arizona State University

What does this have to do with stars? As the Earth moves around the Sun, we view the stars from a continuously changing position. Thus, the nearby stars appear to change positions compared to the distance stars.



The measurements that you made above are quite similar to those made by astronomers in order to measure the distances to nearby stars. The big difference is that even the nearest stars are quite far away compared to the diameter of the Earth's orbit around the Sun.

Because the stars are so far away, the parallax angle of even the nearest star is extremely small. The nearest star, Proxima Centauri, has a parallax angle of only 0.75" (arcseconds), which is only 1/4800 of a degree. Using such small angles in the formula we used above is somewhat difficult. Thus, astronomers have created a special unit, the *parsec*, for working with the distances to the stars. A parsec is the distance at which a star will have a parallax shift of exactly one arcsecond as observed from the Earth; a parsec is also equal to 3.26 light-years. Using the units of *parsecs* for distances and *arcseconds* for the parallax angle, we may rewrite the distance formula in the following simple way:

$$D = 1/p$$

where D is the distance to the star in *parsecs* and p is the parallax angle of the star measured in *arcseconds*. (The definition of the parsec in this way is the reason why we use only the angle *p*, and not the full parallax shift *2p*, when we talk about parallax angle.) Thus, if a star has a parallax shift of 0.5", its distance is 2 parsecs.

Max-Planck-Gesellschaft

Defeated by the tides

The Copernican worldview has prevailed - not, however, Galileo’s theory of the tides.

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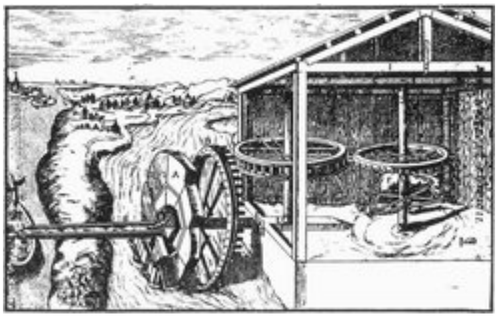
Galileo Galilei

Clearly inspired by the behaviour of water when boats come to a halt, Galileo Galilei concluded that the ebb and flow of the tides resulted, similarly, from the acceleration and deceleration of the oceans. This, in turn, was caused by the movement of the Earth around the Sun, and its rotation on its own axis. However, Galileo was completely mistaken in this theory.

Text: Jochen Büttner



Learning from technology: When barges transporting freshwater dock in the harbour, the water they contain continues to slosh forward and back. This inspired Galileo Galilei to develop his theory of the tides. The image shows one of these barges being loaded with its cargo from a pumping station.

After the discoveries he made with his telescope, Galileo Galilei embarked on an increasingly urgent quest for proof of the Copernican worldview, which placed the Sun rather than the Earth at the centre of the universe. In his explanation of the tides, he believed that he had finally confirmed that the Copernican view was correct: his theory of the tides also rounded off the arguments in support of Copernicus, which he presented in his controversial work *Dialogue Concerning the Two Chief World Systems* in 1632.

Together with his friend Paolo Sarpi, Galileo had observed what happens when the barges that transported freshwater to Venice were brought to a sudden halt for docking: “keeping its impetus”, the water in the hull – as opposed to the boat itself – “will run forward toward the prow where it will rise perceptibly”. And thereafter slosh forward and back for some time. Accordingly, in Galileo’s view, high and low tides could result from the forward and backward flow of water in sea basins when the latter are decelerated or accelerated. But by which means?

As a staunch Copernican, Galileo had an explanation at hand: the tides are propelled by the dual motion of the Earth around the Sun and on its own axis. Because the direction of rotation of the Earth's annual and daily movements are the same, their speeds accumulate on the side of the Earth turned away from the Sun. The opposite happens on the side facing the Sun, he argued. Between these points, the seawater is either accelerated or decelerated, just like the water in the barge.

The student of nature elaborated further. To establish how the water flows backwards and forwards in the sea basins, he adopted the comparison with a giant pendulum. The National Library in Florence houses a 200-page-thick bundle of manuscripts containing Galileo's notes on questions concerning motion, including calculations, tables and sketches.

An unusual thought experiment can be found on page 154r: Galileo imagines a gigantic pendulum, the length of which corresponds to the Earth's radius. He assumes that this Earth pendulum swings back and forth in six hours and examines whether this assumption can be reconciled with the quantifiable period of oscillation of a ten-metre-long pendulum, for example a swinging light that hangs from the ceiling of a church.

As the manuscripts show, his attempt to extrapolate the period of the tides through the comparison with a pendulum came to nothing. In any case, Galileo did not find any conclusive explanation for the regularity with which high and low tide recur at a delay of around 50 minutes day by day.

Nonetheless, he published the *Dialogue* - and doubts were quickly expressed about his theory of the tides. Worse still: Although the Roman censor had initially authorised the printing of the *Dialogue*, in late 1632, Galileo was accused of having contravened the anti-Copernican Decree of 1616 with this publication. The scientist was ordered to deny Copernican teachings and was condemned to lifelong house arrest.

In the centuries that followed, the *Dialogue* became a symbol of Galileo's commitment to the freedom of scientific thought. It was not until 1992 that Pope John Paul II described Galileo's conviction by the Inquisition as a “painful misunderstanding”.

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