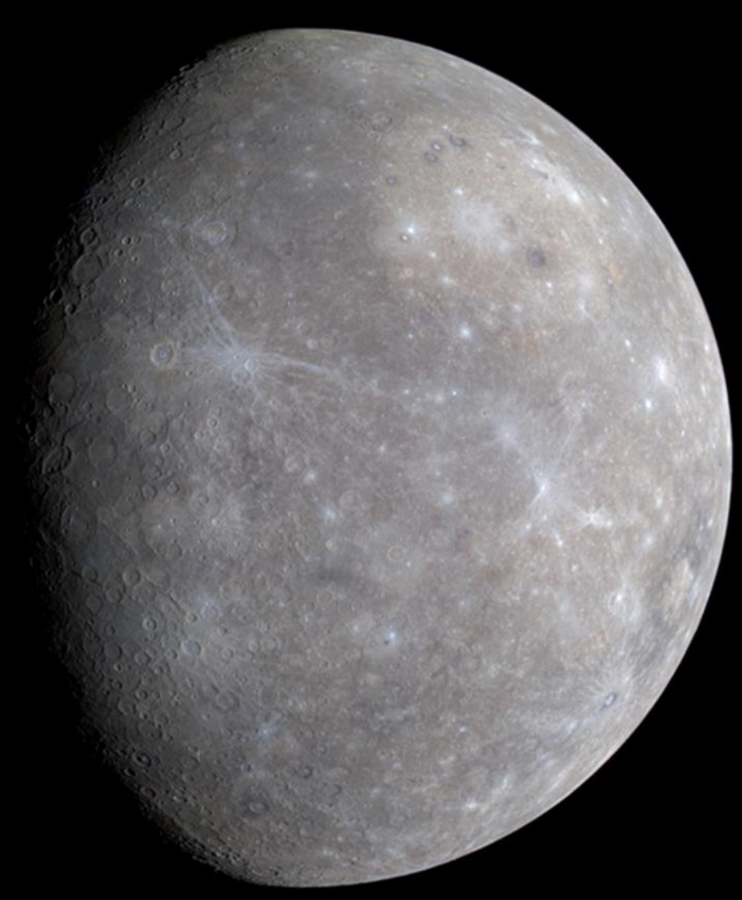
MERCURY vs. THE MOON

MERCURY IN TRANSIT

Mercury and Earth's Moon have much in common

(Relative sizes are to scale)



Mercury

Table 1: Numbers Describing Mercury and the Moon

Quick Numbers	Mercury	The Moon
Radius, km	2,440	1,740
Mass (Earth's Mass)	5.5%	1.2%
Rotation Period (days)	58.6	27.3
Object it Orbits	Sun	Earth
Orbital Period (days)	88.0	27.3
Orbital Tilt*	7.0°	5.1°

The Moon

Figure 1: Planet Mercury and Earth's Moon, to scale. Mercury: MESSENGER (NASA); Moon: Lunar Reconnaissance Orbiter (LRO; NASA)

Definitions:

Radius:	Distance from the center of the object to its surface.
Mass:	How much matter ("stuff") makes up that object. Earth's mass is 6.0×10^{24} kg.
Rotation Period:	How much time an object takes to spin around its own axis once.
Orbital Period:	How much time an object takes to complete one full orbit.
Orbital Tilt:	How much this object's orbit is tilted relative to Earth's orbit around the Sun. *This is more properly referred to as the "Orbital inclination with respect to the ecliptic"
Transit:	And object (such as a planet) "crossing" a star from our perspective.
Solar Eclipse:	When the Moon is between the Sun and Earth and prevents the Sun's light from reaching part of the Earth.
Lunar Eclipse:	When the Earth is between the Sun and Moon, and prevents the Sun's light from reaching the Moon.

Transits and Eclipses – When Worlds Align

Mercury orbits the Sun in less time than Earth does, and so Mercury "catches up" to Earth and passes ("laps") us once every 116 days. But we only see Mercury transit the Sun 13-14 times every century. Why the difference?

The Earth's Moon is between the Sun and Earth every cycle of Moon phases (29.5 days), and the Earth is between the Sun and Moon once each lunar cycle, as well. But there are only 2 to 5 eclipses per year. Why not more?

The answer is the same for both questions:

Mercury and the Moon's orbits are *tilted* relative to Earth's orbit around the Sun.

So two things have to happen in order to see a transit or eclipse:

- The objects have to be in the correct parts of their orbits, so that they form a line, and
- The objects have to be crossing each other's orbits at the same time.

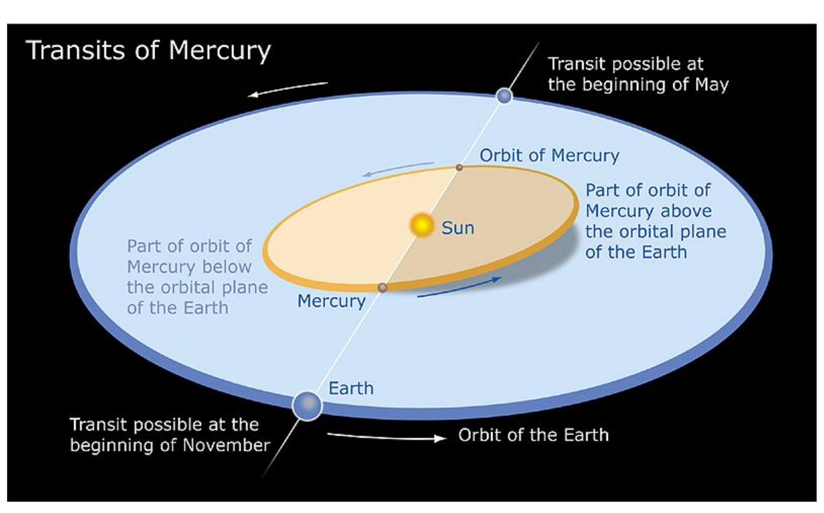


Figure 2: An illustration showing the relative tilt between Mercury's and Earth's orbits. Note that these orbits only cross each other at two points, or "nodes." (Image by European Southern Observatory, ESO)

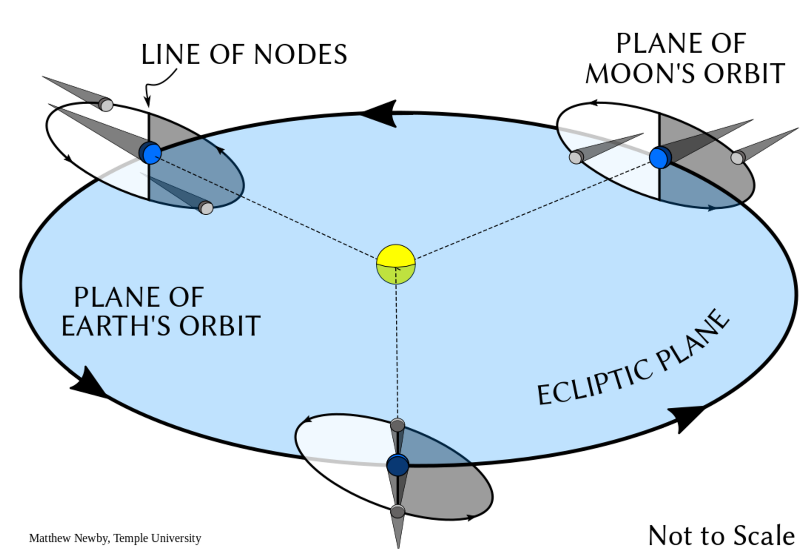


Figure 3: A diagram showing the tilt of the Moon's orbit relative to Earth's orbit around the Sun. Note that eclipses are only possible when the Moon crosses Earth's orbit. Not that the Moon is duplicated at each point in Earth's orbit; this is to show both the New Moon and Full Moon phases, and their shadows, at each location.

When a body (like Mercury) crosses another body's orbit (such as Earth's), the location of that crossing is called a **node**. There are two nodes: an *ascending node,* when the body is moving "up" through the other orbit; and a *descending node*, when the body is crossing "downwards" through the other body's orbit. The line between the two nodes is called the **Line of Nodes**.

Only when both bodies are on the line of nodes, and that line points to the Sun, can a transit or eclipse occur (See Figures 2 and 3). This makes transits and eclipses much less common than we might initially expect.

Normally, during a Full Moon or New Moon phase, the Moon's shadow does not fall on the Earth (or vice-versa), and no eclipse occurs (Figure 4, top).

When the line of nodes points towards the Sun during a New Moon phase, the Moon's shadow falls on the Earth and we get a **Solar Eclipse** (Figure 4, middle). Note that the Moon's shadow does not cover the entire Earth – only a small "stripe" across the Earth's surface will experience a total Solar eclipse!

Finally, when the line of nodes points towards the Sun during a Full Moon phase, we will see a **Lunar Eclipse** (Figure 4, bottom). The Earth's shadow is much bigger than the Moon's shadow, and so the entire Moon can be eclipsed at once. This bigger shadow also makes it easier for a Lunar eclipse to occur.

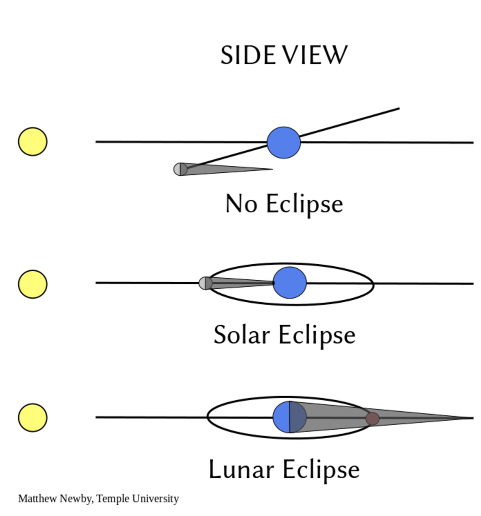


Figure 4: A diagram illustrating the Earth-Sun-Moon configurations that lead to eclipses. Top: a New Moon phase without an eclipse. Middle: A New Moon phase during a Solar eclipse. Bottom: A Full Moon phase during a Lunar eclipse. The Moon may appear red during Lunar eclipses due to light refracted through Earth's atmosphere.

Table 2: Transits and Eclipses

Event	Frequency of Events	Previous Event	Next Event
Transit of Mercury	One every 6 – 13 years	May 9, 2016*†	November 13, 2032*
Transit of Venus	One pair (8 years apart) every 105 or 120 years	June 6, 2012	December 10, 2117
Solar Eclipse	One every 18 months	July 2, 2019†	December 26, 2019†
Lunar Eclipse	2 to 5 per year	July 16, 2019†	January 10, 2020†

*The November 11, 2019 transit of Mercury is not included here.
† Not visible from North America.

Gravity Changes How Planets and Moons Rotate

Since the force of gravity changes with distance, and real objects have size, one side of a body is pulled more strongly than the other side. These "stretching" forces are known as **tidal forces.** The Moon's tidal forces on the Earth are responsible foe our ocean tides.

When this pull is from a nearby, massive body, the tidal forces will pull on one side strongly enough that the smaller body will be "locked" so that only one side faces the large object. This phenomenon is known as **tidal locking**.

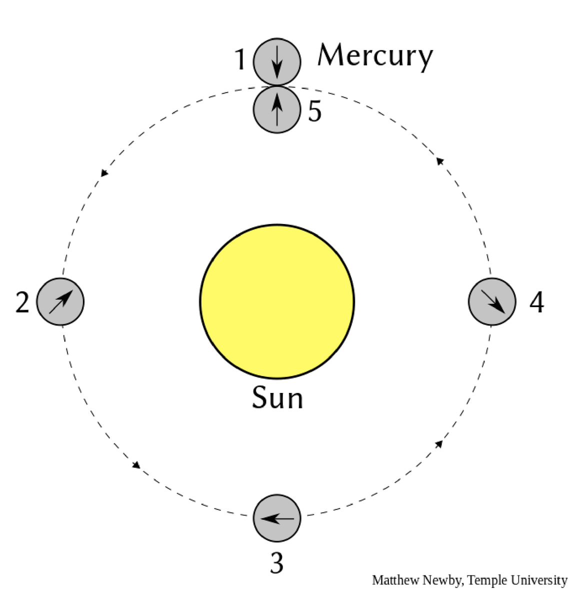


Figure 5: Mercury's rotation as it orbits the Sun. Every time Mercury orbits the Sun once, it rotates 1 and half times around its own axis.

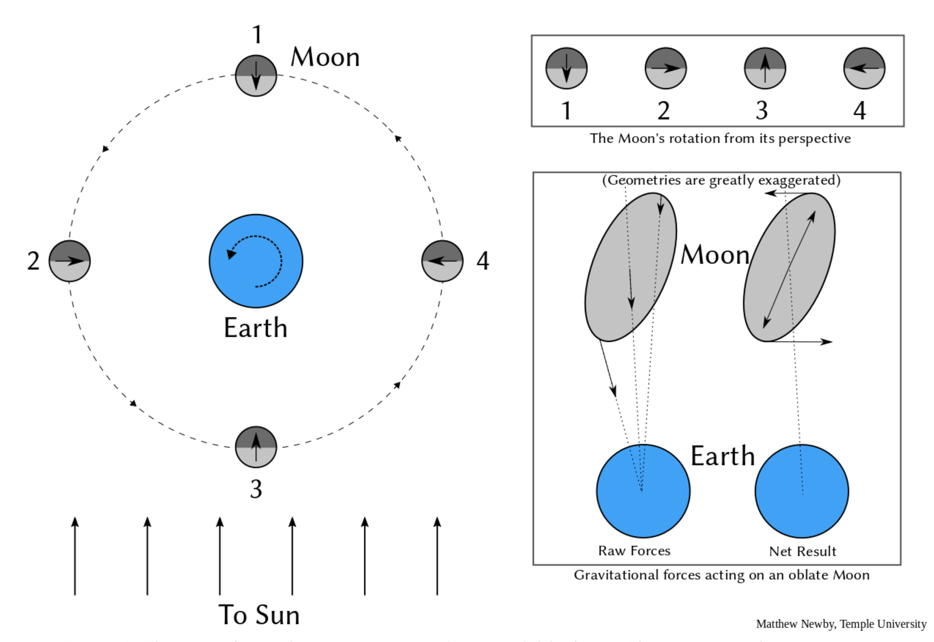


Figure 6: The Moon's synchronous rotation due to tidal locking. The arrow on the Moon points towards the near side of the Moon, which is the only side that can be seen from Earth. The shading shows the part of the Moon illuminated by the Sun at each point in its orbit. The bottom-right panel illustrates how gravity results in tidal forces that stretch and try to lock a smaller body.

The Moon rotates on its axis exactly once per orbit around Earth, keeping only one side facing Earth at all times. This 1:1 *spin-orbit resonance* is due to tidal locking. Earth is the only place in the universe that does not get to see every side of the Moon!

Planet Mercury is not perfectly tidally-locked to the Sun, but tidal forces have locked Mercury into a 3:2 *spin-orbit resonance*. This means that Mercury rotates 3 times around its own axis for every 2 orbits around the Sun.

No Atmosphere, Plenty of Craters

Both Mercury and the Moon have no atmosphere - other than a few random atoms hopping around. They also don't have the exciting geological activity the Earth has: no volcanoes, plate tectonics, or lava flows for either one. With no atmosphere for weather, and no interesting geology to shuffle things around, Mercury and the Moon have no way to modify their own surface features. This means that changes stick around for a very, very long time.

Not only will astronaut footprints stay on the Moon for (almost) forever, but Mercury and the Moon keep a record of the history of our Solar system on their surfaces: craters and other impact features! These craters won't go away unless erased by new craters, or molten rock. Astronomers use craters to learn about what the early Solar system was like.

Big flat areas on the Moon ("mare") and Mercury ("basins") are evidence of molten rock flows that erased previous craters. Either these worlds were geologically active in small areas recently (as in, less than 1 billion years ago), or they were hit by asteroids so large that they cracked and melted the world's crust. Astronomers are finding evidence that the second hypothesis may be the correct one.

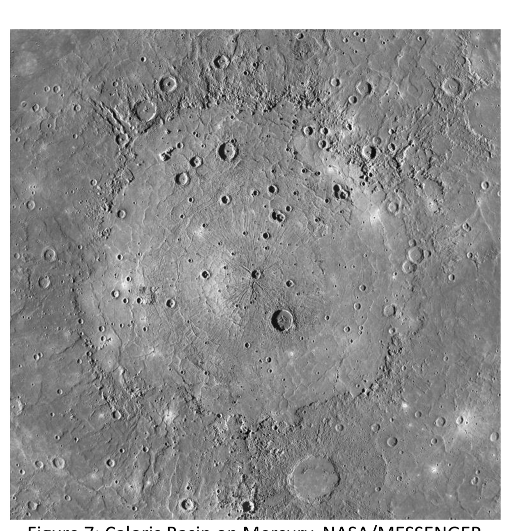


Figure 7: Caloris Basin on Mercury. NASA/MESSENGER

Figure 8: Chaotic ("Weird") Terrain on Mercury, on the opposite side from Caloris Basin. NASA/JPL.

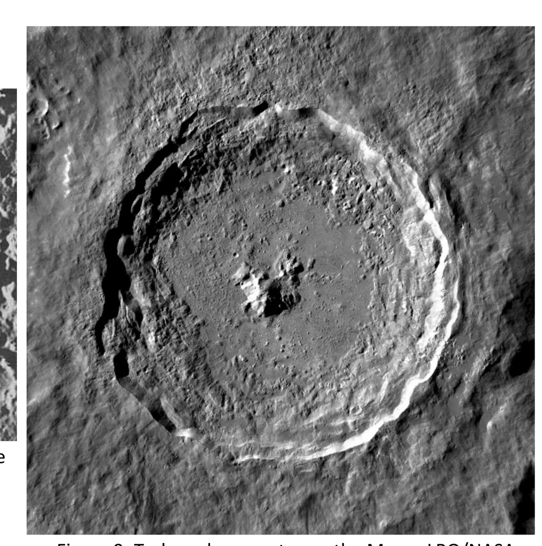


Figure 9: Tycho, a large crater on the Moon. LRO/NASA

Caloris Basin – a Massive Impact?

Caloris Basin (Figure 7) is one of the largest impact features in the Solar system, being 1,550 km in diameter. Compare that to Mercury's radius in Table 1! Caloris Basin (from Latin for "heat" – like "calorie") was created by an impact so large that it appears to have cracked the crust and let molten rock pour out, creating to smooth surface (with some newer craters on top of it).

On the exact opposite side of Mercury from this basin (the antipode) there exists Chaotic (or "Weird") Terrain, full of hills and odd, bumpy features. This appears to have been created by the same huge impact that created Caloris Basin – sending shockwaves straight through to the other side of the planet!

Moon Crater Tycho

Tycho (named for astronomer Tycho Brahe) is a large crater on the Moon with some "textbook" features (Figure 9). It has a circular ring, blasted into the Moon's surface by a large asteroid impact that occurred approximately 108 million years ago. At the center is a "rebound peak" in the middle, where impact material bounced back upwards. The smooth terrain inside the crater shows that the surface was melted by the impact. And finally, large "rays" of bright material extend out in spokes from the center.

If you want to see the rays, try finding Tycho on the big picture of the Moon at the top (Figure 1)! Hint: It's near the bottom, and a little to the left.

Credits

Poster design and text by Matthew Newby, Temple University. Figures and tables not credited in captions were created by Matthew Newby, Temple University, from Inkscape vector graphics program. The Mercury in Transit event at Temple University is a joint effort between the College of Science and Technology, the Charles Library, and the Department of Physics.