

Missing Moon



Premise

It is thought that the impact of planet **Theia** colliding with a young Earth resulted in the formation of the Moon.

But...

What if the impact never happened?

What if Theia had missed the Earth?
Would we miss the Moon?



This talk looks at an "alternative history" of a moonless Earth.

Why Does It Matter?

One of the biggest questions humankind can ask...
Are we alone, or is there life somewhere 'out there' in the Universe?



There are ~20 billion stars like our Sun* in the galaxy. If only ~10% of these stars have Earth-like planets, that means ~2 billion in total.



"If it's just us, seems like an awful waste of space." [Carl Sagan]

If Earth-like planets need a large moon to ensure that the planet is hospitable to life, then the probability of life 'out there' goes down.

Contents

Without the Moon, what would be different here on Earth?

- Tidal Forces
- Axial Tilt
- Magnetic Field
- Asteroid Impacts
- Eclipses

...and, just out of mischievous curiosity, ...

What would be different if Theia had hit **Venus** instead of Earth?
How might it have influenced the way we perceive the Universe?

Missing Moon

Disclaimer

This "alternative history" talk contains quite a bit of conjecture.

The opinions are those of the presenter and do not necessarily align with the views of...

IOP Institute of Physics



...or, indeed, anybody else.



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Our Companion

The phases of the Moon cycling from New to Full to New



A familiar sight in Earth's skies for billions of years



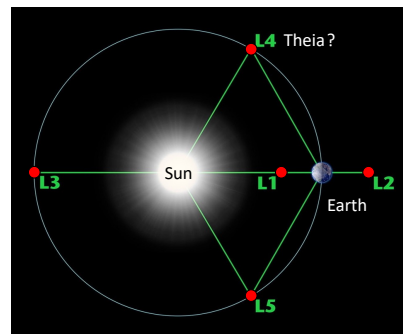
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Origins

It is thought that the impact of planet **Theia** colliding with a young Earth resulted in the formation of the Moon.

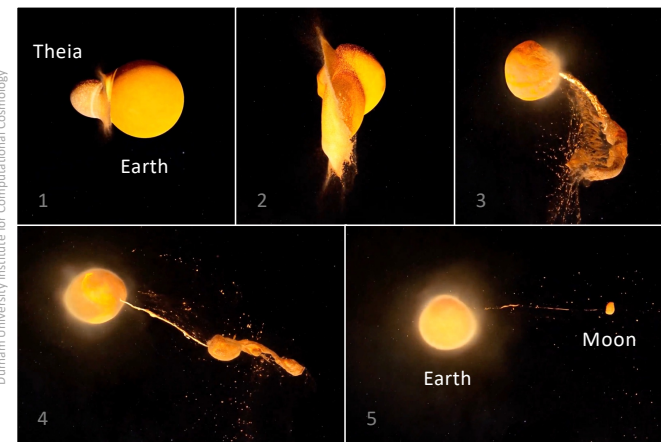
Where did Theia come from?

Maybe one of the Lagrange points of the Earth: L4 or L5.



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Giant Impact Hypothesis



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Missing Moon

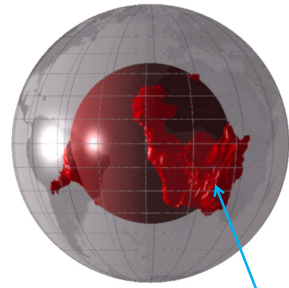
Origins

Seismic waves allow us to probe the interior structure of the Earth.

In the 1980s some odd structures called superplumes were found at the boundary between the **core** and the **mantle**.

One is below Africa, the other is below the Pacific Ocean.

Are these what's left of Theia?



Theia?

Effect on Earth

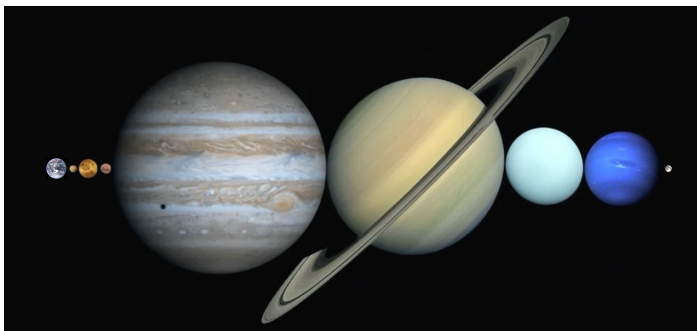
The Moon's mass is only ~1% of Earth's mass, so can it have much effect?



Earth–Moon sizes are to scale

Effect on Earth

The Moon's mass is only ~1% of Earth's mass, so can it have much effect?



Earth–Moon sizes and separation are to scale

TIDAL FORCES

Missing Moon

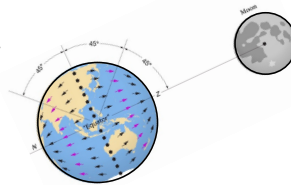
Tides

There are a lot of misconceptions about the origin of tides on Earth.

After browsing various sources on the internet, I concluded that:

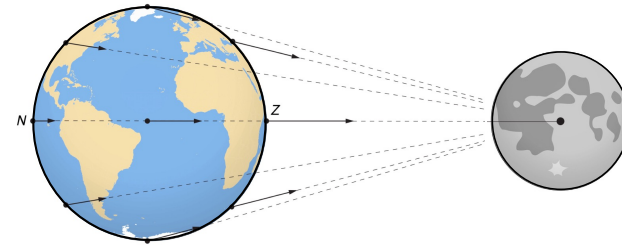
- ~20% don't actually explain why we have tides
- ~40% explain tides correctly
- ~40% don't explain tides correctly

Even some physicists get it wrong
(yes, I know that's hard to believe)
and they really ought to know better.



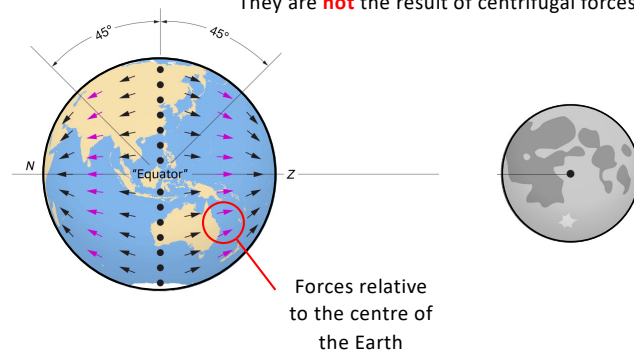
Tidal Forces

Tides are generated by gravitational forces only.
They are **not** the result of centrifugal forces.

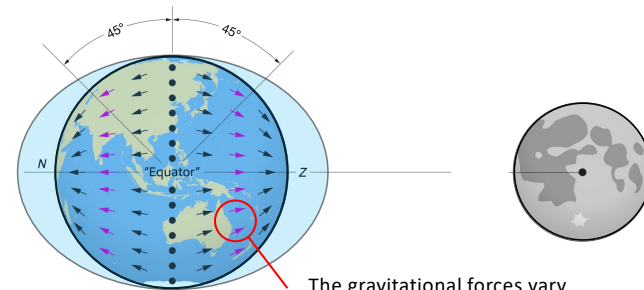


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Tidal Bulges



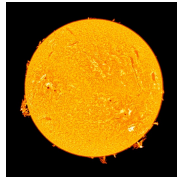
Missing Moon

Missing Moon

So what would happen if we had no Moon?

No tides? X

No lunar tides. ✓

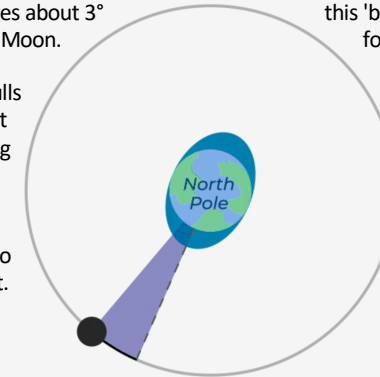


But we would still have **solar** tides. The range of tidal heights would be reduced as solar tidal forces are only about **half** those of the Moon. High tide would be around midday and midnight every day.

Tidal Drag

Earth's rotation carries the tidal bulges about 3° ahead of the Moon.

The Moon pulls on the closest bulge, slowing the rotation of the Earth and sending the Moon into a higher orbit.



The Moon has been applying this 'brake' on the Earth for billions of years, resulting in days getting longer.

Originally a day was ~6 hours.

It is now ~24 hours.

Shorter Days

Without a Moon, the short 6-hour days would have consequences.

Rapid planetary rotation might mean high winds. Jupiter has a 10-hour day and the strong Coriolis forces (that produce typhoons and hurricanes here on Earth) result in cloud belts with very high wind speeds ~500 km/h.

However, Jupiter's weather system is driven by a very strong internal heat source which the Earth lacks, so the wind speeds on Earth would not be so extreme.



Voyager 1 view of Jupiter
Timelapse over 16 Jovian days
(~7 Earth days)

Effect on Oceans

The influence of our Moon on the emergence of life is based on two assumptions:

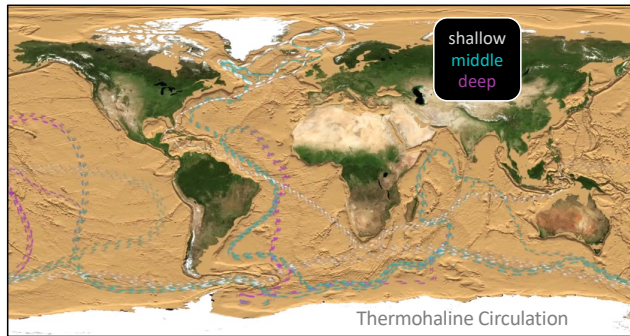
- Life needs a healthy ocean ... and ocean layers need mixing. ✓



- Life needs tidal pools ... to transition from the ocean to land. ✓

Missing Moon

Ocean Mixing



Without mixing of ocean layers at different depths, nutrients would sink to the ocean depths and dissolved oxygen would remain at the surface. Vertical mixing ensures that these are redistributed.

Ocean Mixing

Without a Moon, would we still have a THC and ocean mixing?

The THC is driven by many factors, including ...

- Variations in temperature and density (due to saltness)
(**thermo**) (**haline**)
- Surface winds
- Tides

Even with smaller (solar only) tides, the potentially higher winds could compensate for this and so ensure healthy ocean mixing.

Tidal Pools

Tidal pools were probably an important element in the evolution of life, especially half a billion years ago.



The ever-changing environment of the inter-tidal zones led to an acceleration of evolutionary specialisation.

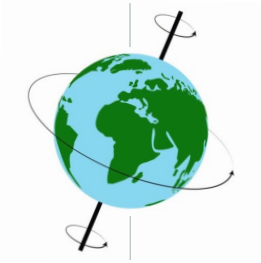
Would smaller tides impede evolution? Probably not, as tidal pools were only one way to transition to land (rivers, marshes, swamps).

AXIAL TILT

Missing Moon

Axial Tilt

Over hundreds of million of years the axial tilt (or obliquity) of the Earth has varied over a relatively narrow range of 22.1° – 24.5° .



23.4°

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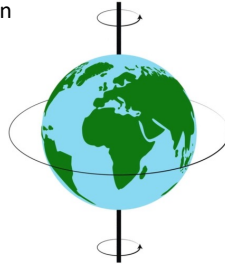
25

Axial Tilt

This is because the Moon has a stabilising influence on the axial tilt. It 'anchors' the tilt at the current value of 23.4° , give or take 1° .

Without a Moon, what could happen to the tilt?

In principle, it could swing between extreme values of 0° to 90° .



0°

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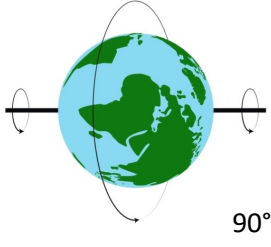
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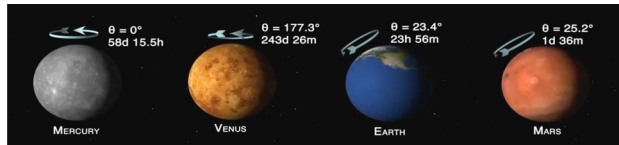
90°

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Axial Tilts of Planets

Does this happen for any planets in the solar system that don't have a large moon? Are their tilts unstable?



Mercury? Venus?

No. Their tilts are stabilised by solar tides.

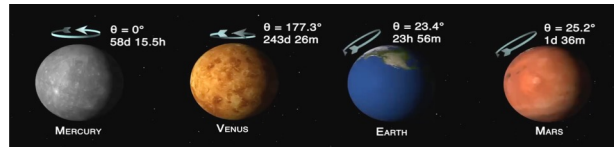
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Missing Moon

Axial Tilts of Planets

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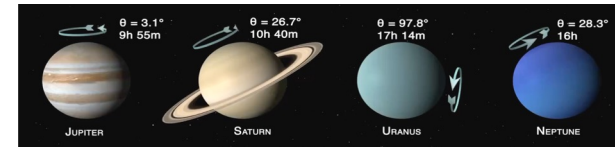


Mars?

Yes. It is thought that the ~25° tilt has varied over millions of years due to the tidal influence of Jupiter.

Axial Tilts of Planets

Does this happen for any planets in the solar system that don't have a large moon? Are their tilts unstable?



The outer planets?

Jupiter and Saturn have relatively stable tilts because of their large masses, but the ice giants' tilts are unstable over billions of years.

Axial Tilt and Seasons

A large axial tilt would mean extreme seasons. ✓

That would make planet Earth uninhabitable. ✗



Climate simulations* of Earth-like planets with high obliquity...

- Global annual mean temperatures of ~14°C
- No net accumulation of snow or ice with obliquity > 23°
- No runaway greenhouse or 'snowball Earth' scenarios

The conclusion: "Most real Earth-like planets should be hospitable to life at high obliquity."

Axial Tilt and Habitability

So high obliquity is **not** inhospitable to life.

Simulations* of a moonless Earth have shown ...

- The obliquity remains within the range ~20°–25° over time periods of hundreds of millions of years
- Faster rotating Earths are more stable

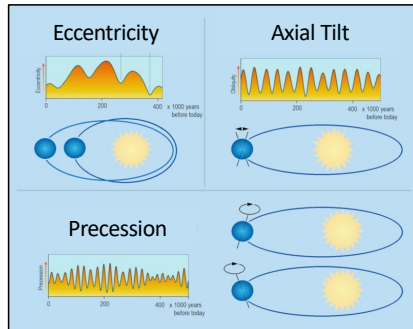


The conclusion: "A large moon thus does **not** seem to be needed to stabilise the obliquity of an Earth-like planet on timescales relevant to the development of advanced life."

Missing Moon

Axial Tilt and Climate

Changes to the Earth's climate follow Milankovitch cycles.



Orbital Eccentricity
(100,000+ years)

Axial Tilt
(41,000 years)

Axial Precession
(26,000 years)

Combined, these
three cycles trigger
Earth's ice ages.

Missing Moon

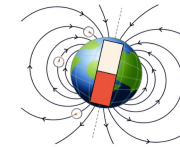
Without a Moon, ice ages might be severe – but not unsurvivable.
(Neanderthals survived multiple ice ages. They adapted to the cold.)



MAGNETIC FIELD

Magnetic Field

The Earth has an iron-nickel core that provides us with a protective magnetic field.



In the following CGI animation we can visualise how it deflected solar radiation during the geomagnetic storm of May 2024.

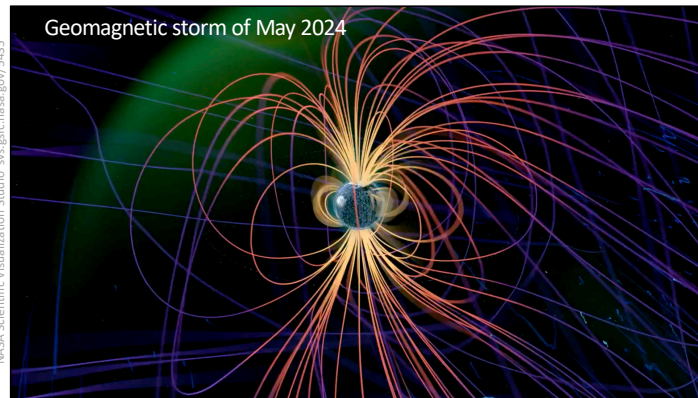
[Aside –

The animation was created by the Scientific Visualization Studio of NASA Goddard Space Flight Center (GSFC). Their web site has thousands of high-quality videos that are well worth looking at: svs.gsfc.nasa.gov/search

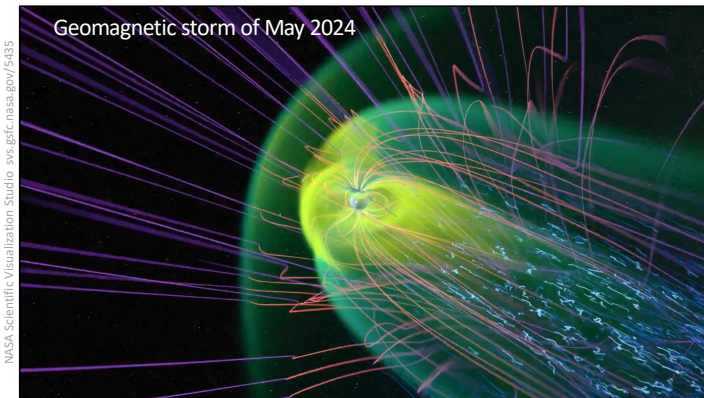
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Missing Moon

Magnetic Field

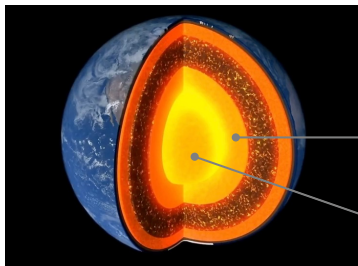
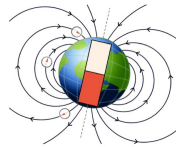


Magnetic Field



At the Earth's Core

This simple drawing doesn't show how the Earth's core generates a magnetic field.

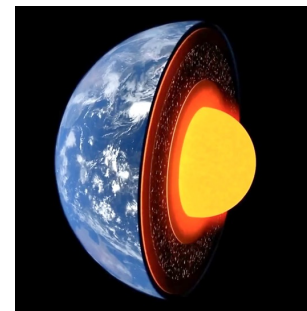


Outer core
~4000 K (liquid)

Inner core
~5000 K (solid)

Geomagnetic Field

It is the liquid **outer** core that is the 'geodynamo'. Heat from the **inner** core keeps the liquid swirling around in a complex motion – liquid metal in motion generates electric and magnetic fields.



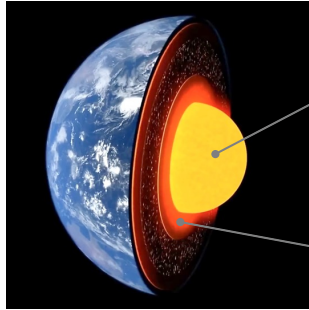
Where does the inner core get its heat from? Some of the heat is from the decay of radioactive atoms (K, Th, U).

Some heat is released because the core is very slowly freezing – the outer core is turning from liquid to solid and the inner core is growing (at an estimated rate of ~1 mm/year).

Missing Moon

Missing Moon

There are two possible consequences of the Earth having no Moon that could weaken the geodynamo and hence make the Earth less hospitable to life.



Did Theia add some iron to the Earth's core and hence add to the geodynamo?

Does the Moon strengthen the geodynamo by stirring up the outer core through tidal action?

Magnetic Field

Did Theia add some iron to the Earth's core?

Theia had a mass of $\sim 10\%$ that of Earth and a composition that was probably similar to Earth. If Theia added iron to the Earth's core then a moonless Earth might have a core $\sim 10\%$ smaller.

The current strength of the Earth's magnetic field $\approx 50 \mu T$

For a moonless Earth this would drop to $\approx 40 \mu T$

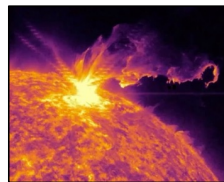
Would this be enough to protect us from solar radiation?

Space Weather

A recent study* of the Earth's habitability (how the magnetic field protected life on Earth from space weather over the past four billion years) found that a magnetic field of...

$5 \mu T$ would protect the Earth during 'quiet' space weather conditions

$30 \mu T$ would protect the Earth from violent coronal mass ejections



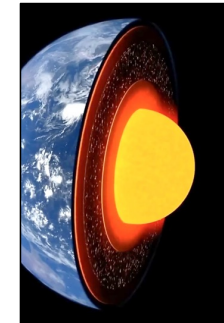
This would indicate that if Theia had missed the Earth then the geodynamo might have been a bit weaker, but not by enough to cause significant problems for the evolution of life.

Magnetic Field

Does the Moon strengthen the geodynamo by stirring up the outer core through tidal action?

Some geophysicists think that lunar tides in the outer core might have helped in sustaining the geodynamo over billions of years.

However, the consensus appears to be that convection of heat from the inner core is all that is needed, and that tides make no contribution.



Missing Moon

Missing Moon

Do any other planets have a magnetic field, even if they don't have a large moon?

Just to confuse matters, Ganymede (the largest moon of Jupiter) also has a magnetic field.

NASA MISSIONS
TO ALL EIGHT PLANETS IN OUR SOLAR SYSTEM, PLUS PLEISTO

Mercury MESSENGER	Venus MAGNETIC	Earth OCCURS
Mars Viking Cluster	Jupiter Galileo, Juno, Europa, etc.	Saturn Cassini
Uranus Voyager 2	Neptune Voyager 2	Pluto New Horizons

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ASTEROID IMPACTS

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Asteroid Impacts

Near Side

Far Side

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Asteroid Impacts

The far side of the Moon shows much more cratering than the near side.

Does that mean it has acted as a 'shield' protecting the Earth?

Geometrically, its apparent area is only a tiny fraction (5 ppm) of the whole sky. Given that its mass is only ~1% that of Earth, its gravity would not deflect any asteroids by a significant amount.

The difference in crater density between the near and far sides is a result of the near side being resurfaced by lava flooding the maria (impact basins).

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Missing Moon

ECLIPSES

Eclipses

Without the Moon there would of course be no eclipses.



No one would experience the awesome sight of a total eclipse of the Sun.



APOD 20 Aug 2008

No eclipses of the Moon would mean no observations of the curved shadow of the Earth, confirming its spherical shape.

Trivia

Without a Moon ...

No Mondays!

No months



With ~1000 days in a year would a year be divided into 10x10x10 days?

No werewolves



No moonlanding conspiracies



Confused sea turtles

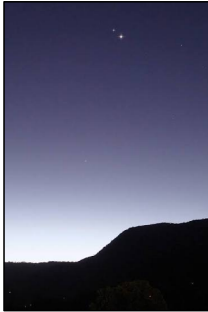


VENUS

Missing Moon

Venus Epilogue

What would be different if Theia had hit **Venus** instead of Earth? How might it have influenced the way we perceive the Universe?*



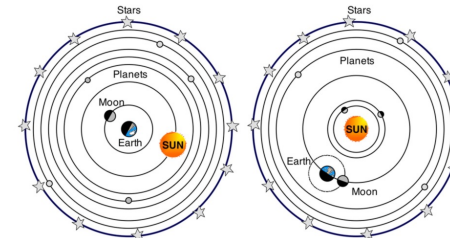
Venus has a similar mass and composition to Earth, so the impact of Theia might have produced a moon similar to our Moon.

Assuming life on the moonless Earth had evolved into humans, what would we have seen of this Venusian moon?

It would appear as a first-magnitude 'star' next to Venus, going back and forth as it orbited, up to about 10–20 arcmin from the planet.

Venus Epilogue

The motion of the moon would be easily visible to the naked eye. Perhaps astronomers in one of the early civilisations, such as the Sumerians or Babylonians, would observe this motion and conclude that some objects in the sky do NOT move around the Earth.

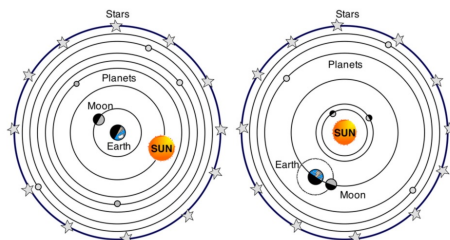


Geocentric Model

Heliocentric Model

Venus Epilogue

In reality, it was the invention of the telescope that allowed us to see moons orbiting Jupiter. This triggered the change from the geocentric to the heliocentric model of the solar system and catalysed the scientific revolution and the age of reason (in the late 1600s).

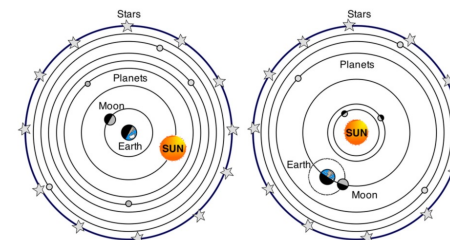


Geocentric Model

Heliocentric Model

Venus Epilogue

If Venus had a moon that was visible to the naked eye, perhaps this profound paradigm shift in human thought and understanding would have been kick-started many *thousands* of years earlier!



Geocentric Model

Heliocentric Model

Missing Moon

Summary

TIDAL FORCES

Would a missing Moon mean no life? **No**

AXIAL TILT

Would a missing Moon make Earth inhospitable to life? **No**

MAGNETIC FIELD

Would a missing Moon make the field too weak to protect us? **No**

ASTEROID IMPACT

Would a missing Moon make Earth more of a target? **No**

ECLIPSES

Would a missing Moon mean no eclipses? **Yes** (shame)



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Final Thoughts

Some people believe in the 'Rare Earth hypothesis':

Life **NEEDS** a large moon... so the Earth is unique... we are alone.

I would argue that a missing Moon does **NOT** mean no life.

Earth is not unique. There are billions of Earth-like planets in the galaxy, so even a very small percentage is a very big number.

The cosmos teems with complex life.



Final Thoughts

So if Theia missed the Earth, would we miss the Moon?

In terms of the evolution of life, no.

But, if we (humans) evolved with a missing Moon, well...

...it just wouldn't be the same without it.



MISSING MOON

www.liverpool.ac.uk/~sdb/Talks

Dr Steve Barrett

UoL 26 Aug 2026

