VNIVERSITAT DE VALÈNCIA Facultat de Magisteri

Natural sciences for schoolteachers
LESSON 2:
Earth in the Universe

Contents

Astronomical observations

Throughout history, people have attempted to describe and explain the motion of celestial bodies using **astronomy**.

Astronomy **was** used for: obtaining bearings, sailing, measuring time, establishing calendars, managing farming, etc.

Despite being one of the oldest sciences, astronomy still continues to arouse great interest because it plays an important role in the search for the **origins of human beings**.

Moreover, **observing the night sky** is an enjoyable activity.

Image: Y. Beletsky (LCO)/ESO
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Astronomical observations

It is now almost impossible to observe the night sky from towns or cities due to **light pollution**.

Image: Dmitry Avdeev
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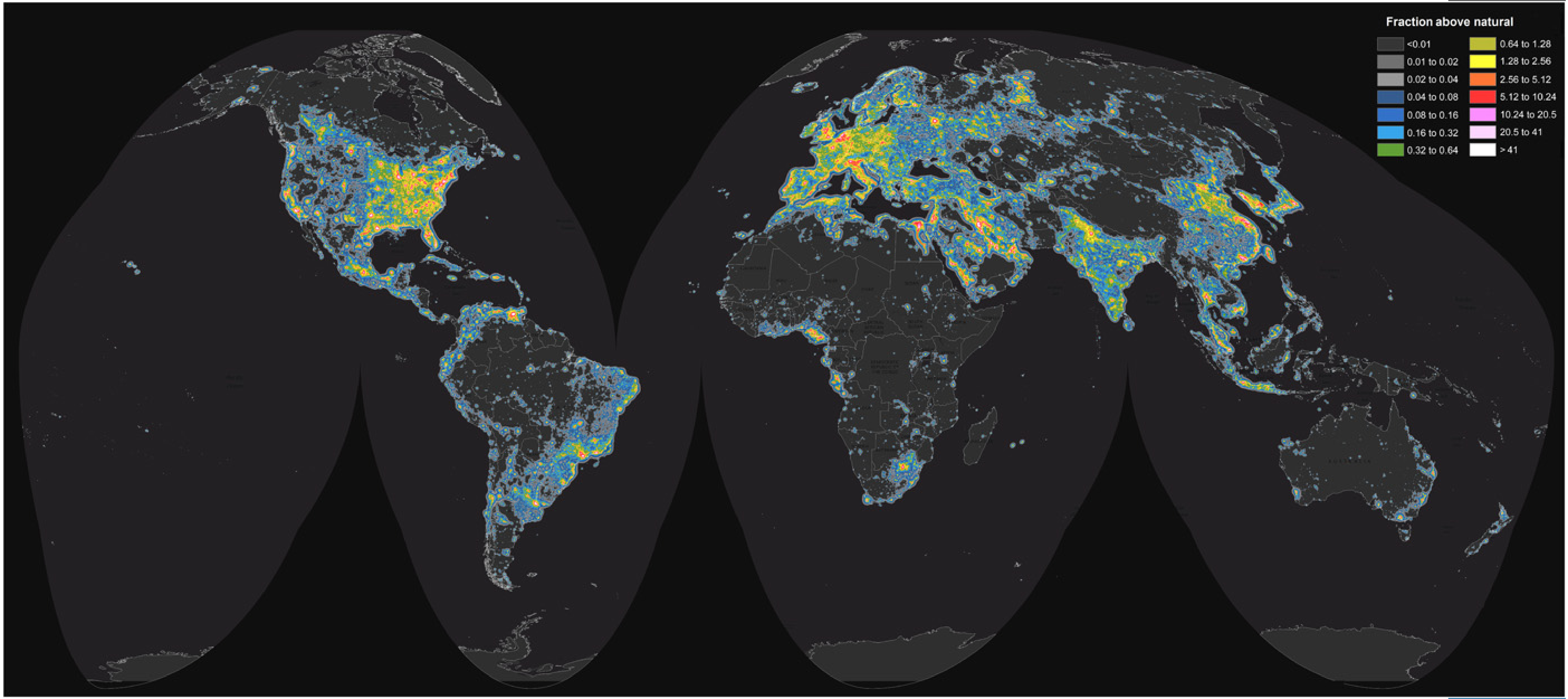
Astronomical observations

It is now almost impossible to observe the night sky from towns or cities due to **light pollution**.



Fabio Falchi et al. (2016). The new world atlas of artificial night sky brightness. Science Advances , 2: e1600377.

Astronomical observations

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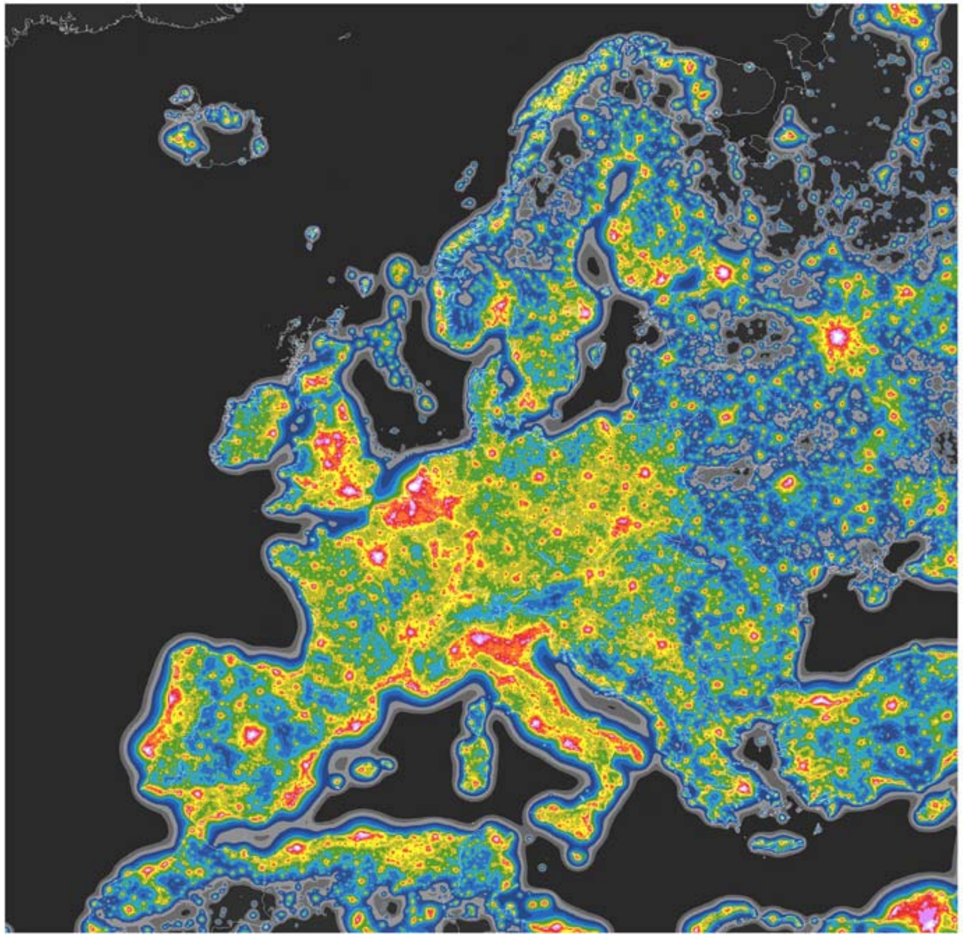

Fabio Falchi et al. (2016). The new world atlas of artificial night sky brightness. Science Advances , 2: e1600377.

Astronomical observations

UNESCO* has formally declared that **the night sky is a right of future generations**.

The **Declaration in Defense of the Night Sky and the Right to Starlight** (La Palma, 2007) states that:

An unpolluted night sky that allows the enjoyment and contemplation of the firmament should be considered an inalienable right of humankind equivalent to all other environmental, social, and cultural rights, due to its impact on the development of all peoples and on the conservation of biodiversity.

* *United Nations Educational, Scientific and Cultural Organization*

Astronomical observations

Constellations

Looking at the sky, most stars seem to retain their relative position.

Ancient civilizations (such as the Babylonians and Greeks) decided to join some of these stars with imaginary lines, creating virtual silhouettes on the celestial sphere. These groupings of stars are the **constellations**.

Imagination allowed people to associate these groupings of stars with animals, mythological figures, etc.

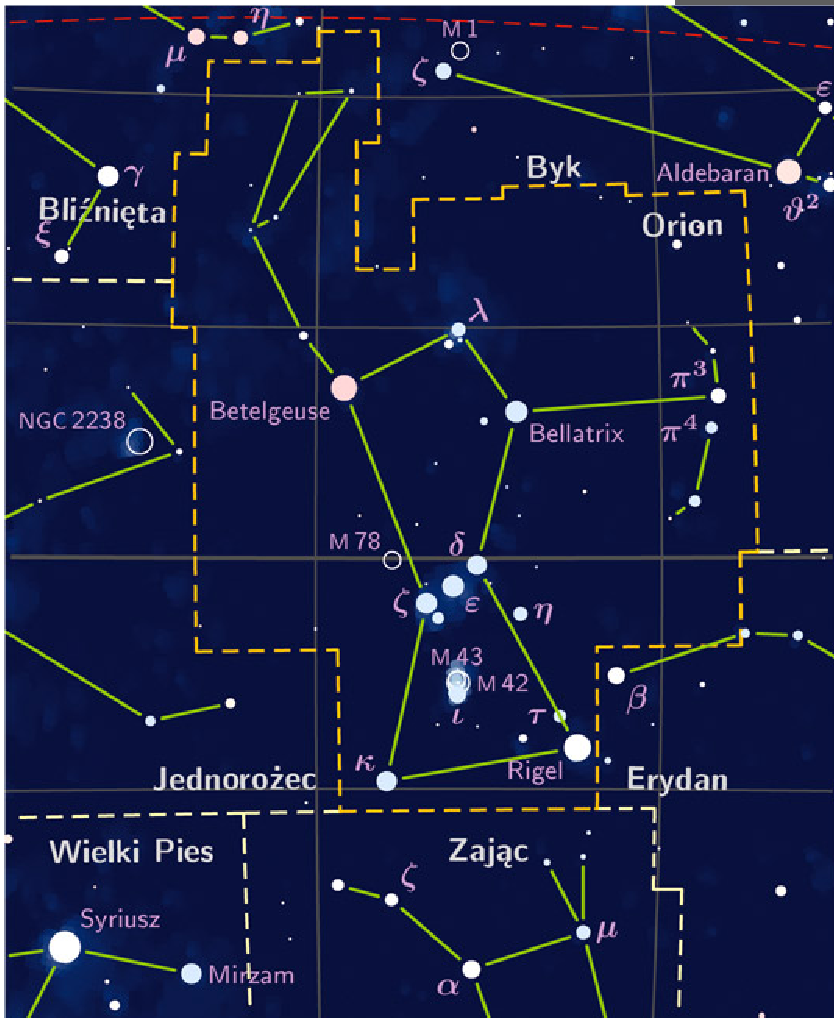

Image: Blueshade
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Canes Venatici
Berenices
Ursa Major
Camelopardalis
Cassiopeia
Andromeda
Leo Minor
Lynx
Perseus
Triangulum
Capella
Pisces
Aries
Auriga
Uranus
Leo
Cancer
δ-Cancrids
Gemini
Taurus
Aldebaran
Cetus
Sextans
Canis Minor
Procyon
Betelgeuse
Orion
Monoceros
Hydra
Rigel
Sirius
Lepus
Eridanus
Canis Major
Fornax
www.stellarium.org
Earth, Valencia, 0m
FOV 138°
67.5 FPS
2017-02-01 22:00:00 UTC+01:00

Astronomical observations

Constellations

Different cultures and civilizations gave different names to these constellations. For example, the **Big Dipper** (US) is also known as:

- *Plough* (UK)
- *Grande Casserole* (France)
- *El Carro* (Spain)
- *Grande Carro* (Italy)
- *Großer Wagen* (Germany)
- 北斗七星 (celestial bureaucrat) (China)

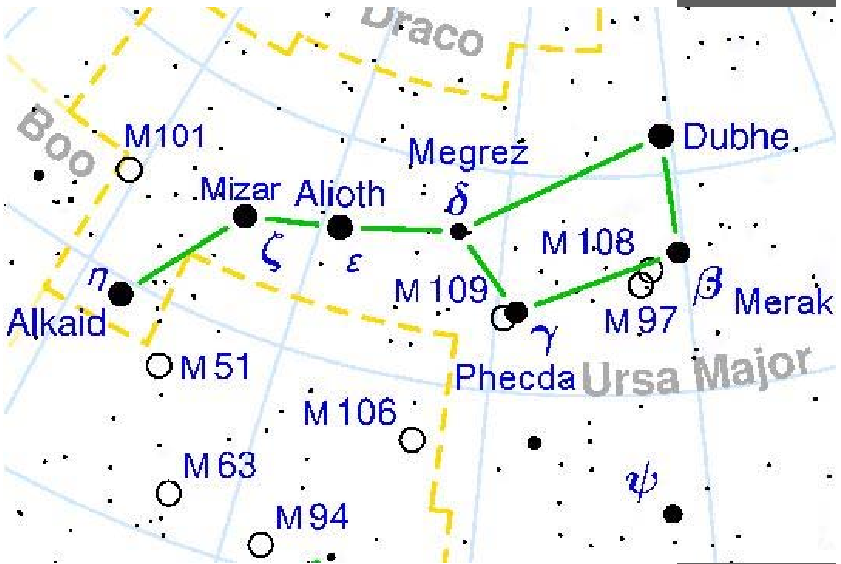

Image: SAE1962

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Astronomical observations

Constellations

The stars of a constellation are not in the same plane, and thus their relative position changes with the years.

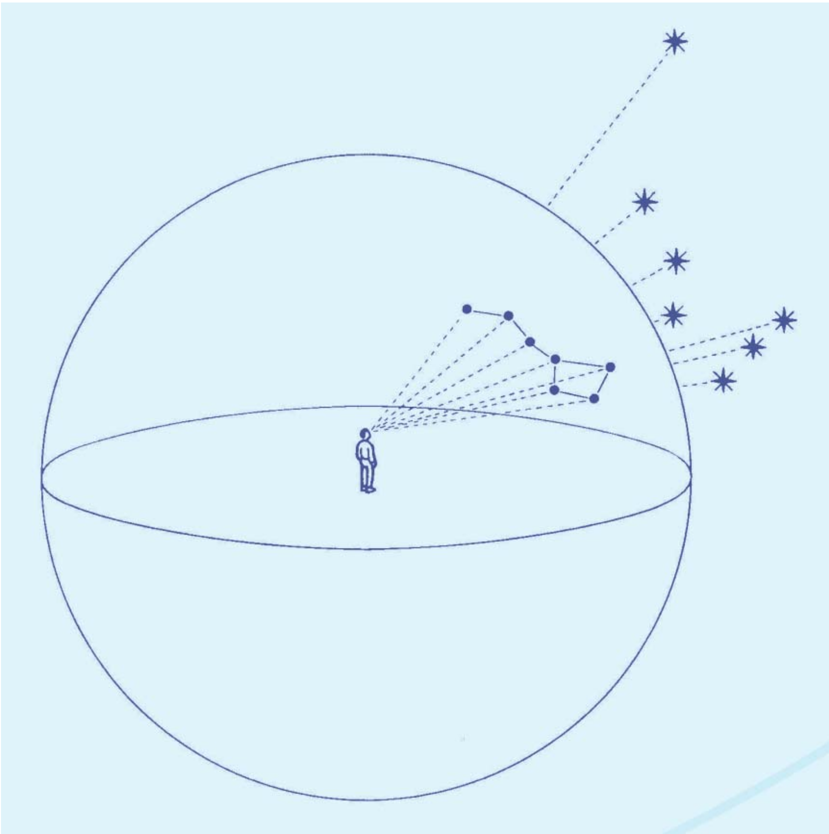
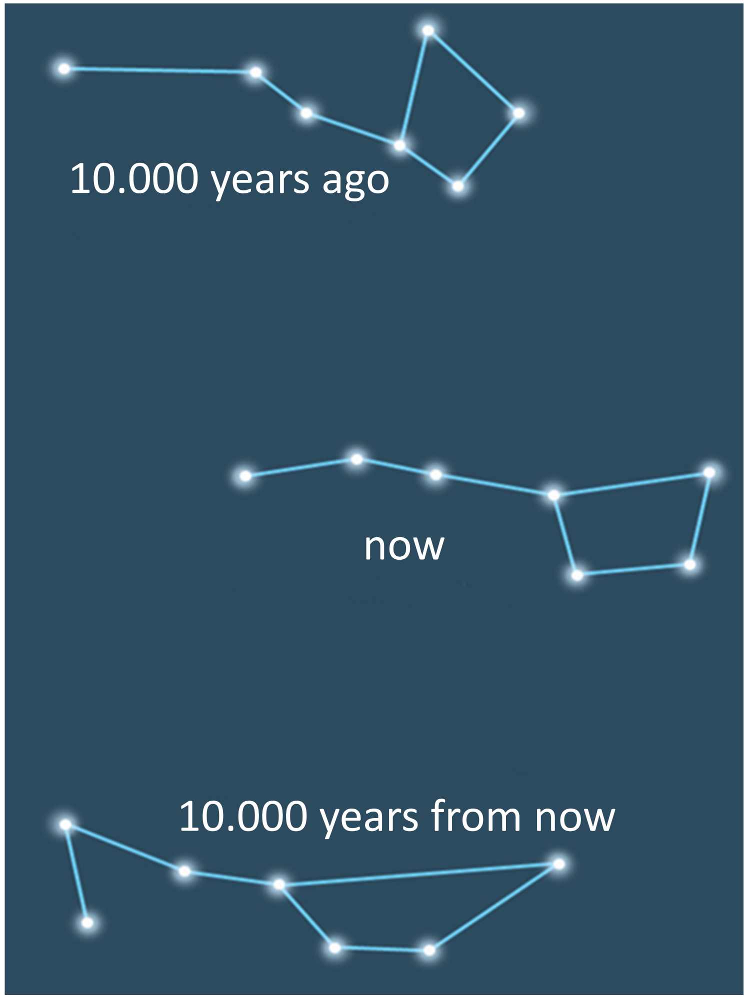


Image: eduCaixa



Astronomical observations

Constellations

A **planisphere** is a star map consisting of two adjustable disks that rotate on a common pivot and can be adjusted to display the visible stars for any time and date.

Image: Wammes Waggel
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Astronomical observations

<u>Constellations</u>

The stars seem to rotate about an apparent fixed point (**celestial pole**), which is an imaginary point in the sky where Earth's axis of rotation intersects the celestial sphere. In the Northern Hemisphere, this point coincides with the **North Star** (***Polaris***).

Image: ESO/A. Santerne
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Astronomical distances

How is the distance to stars measured?

The most accurate way to measure the distance to stars is the **stellar parallax**.

Parallax is the **difference in the apparent position** of an object viewed along two different lines of sight.

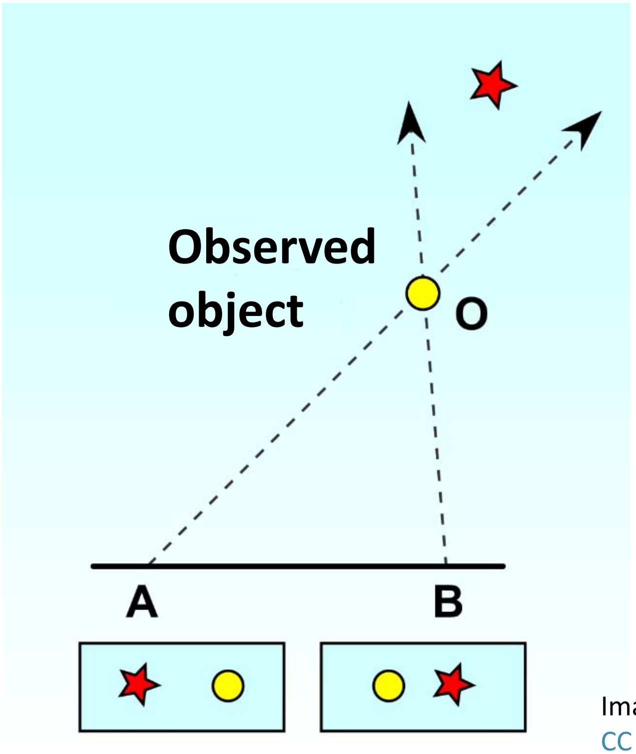

Image: Francisco Javier Blanco González/A.R. Esteve
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Astronomical observations

Astronomical distances

How is the distance to stars measured?

The most accurate way to measure the distance to the stars is the **stellar parallax**.

The position of any nearby star against the background of distant objects appears to change when viewed from two different locations. Once a star's parallax is known, its distance from Earth can be computed trigonometrically.

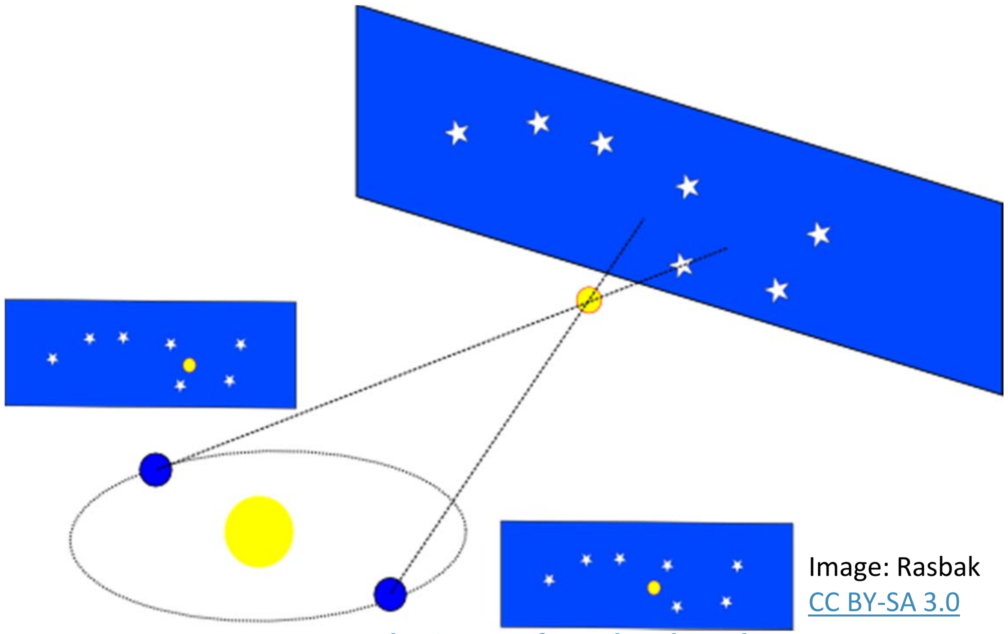

Image: Rasbak
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Astronomical distances

The **astronomical unit (AU)**, which is equivalent to the average distance from Earth to the Sun, is used for measuring distances within the solar system.

1 AU = 150 000 000 km = 1.5×10^8 km

Planet	Distance to the Sun (km)	Distance to the Sun (AU)
Mercury	5.85×10^7	0.39
Venus	1.08×10^8	0.72
Earth	1.50×10^8	1.00
Mars	2.28×10^8	1.52
Jupiter	7.80×10^8	5.20
Saturn	1.43×10^9	9.54
Uranus	2.88×10^9	19.19
Neptune	4.51×10^9	30.06

Astronomical observations

Astronomical distances

The **light-year**, which is the distance that light travels in vacuum in one year, is used for measuring distances between stars.

Since the speed of light in vacuum is 300 000 km/s,

$$\mathbf{1\ light\text{-}year = 9.46 \times 10^{12}\ km}$$

	Distance (light-years)	Comments
Alfa Centauri	4.2	closest star to the Sun
Andromeda	2 500 000	closest galaxy to Earth
Observable universe	93 000 000 000	detectable part of everything generated in the Big Bang

The Moon

The **Moon** is ***Earth's only natural satellite***, and orbits around the planet.

The Moon takes ***27 days, 7 hours and 43 minutes*** to make a complete orbit around Earth.

The Moon does not emit light, but **reflects the Sun's light**.

Image: Luc Viatour / www.Lucnix.be
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Astronomical observations

The Moon

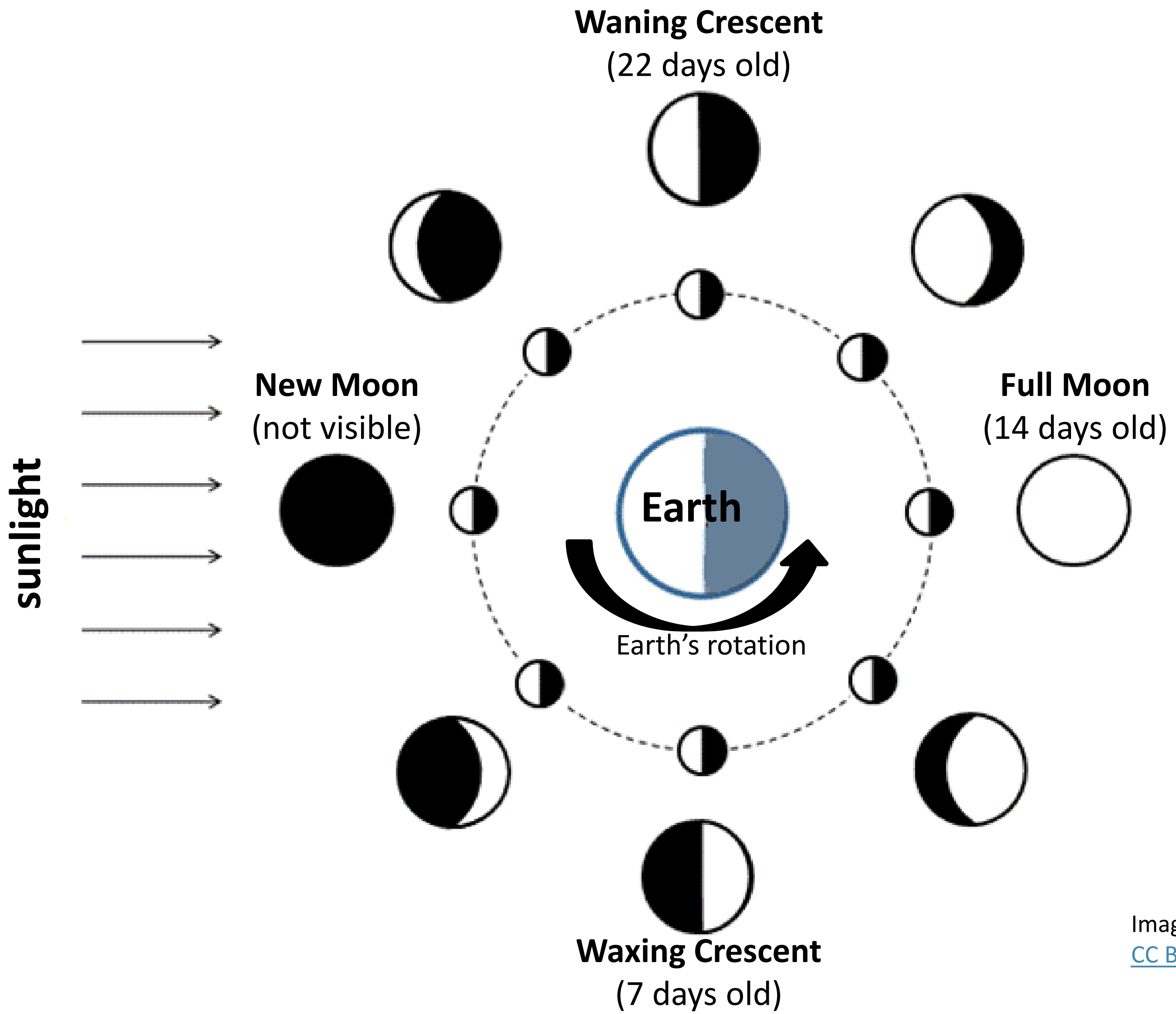

Image: Andonee/A.R. Esteve
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The Moon

The Moon always shows the same face to Earth since the Moon rotates about its axis in about the same time it takes to orbit Earth.

rotation period ~ 27.32 days

orbital period ~ 27.32 days

https://upload.wikimedia.org/wikipedia/commons/5/56/Tidal_locking_of_the_Moon_with_the_Earth.gif

Image: www.astrosurf.com/cidadao/

Astronomical observations

Eclipses

An **eclipse** (Greek for *'abandonment'*) occurs when light from an astronomical object is blocked by another.

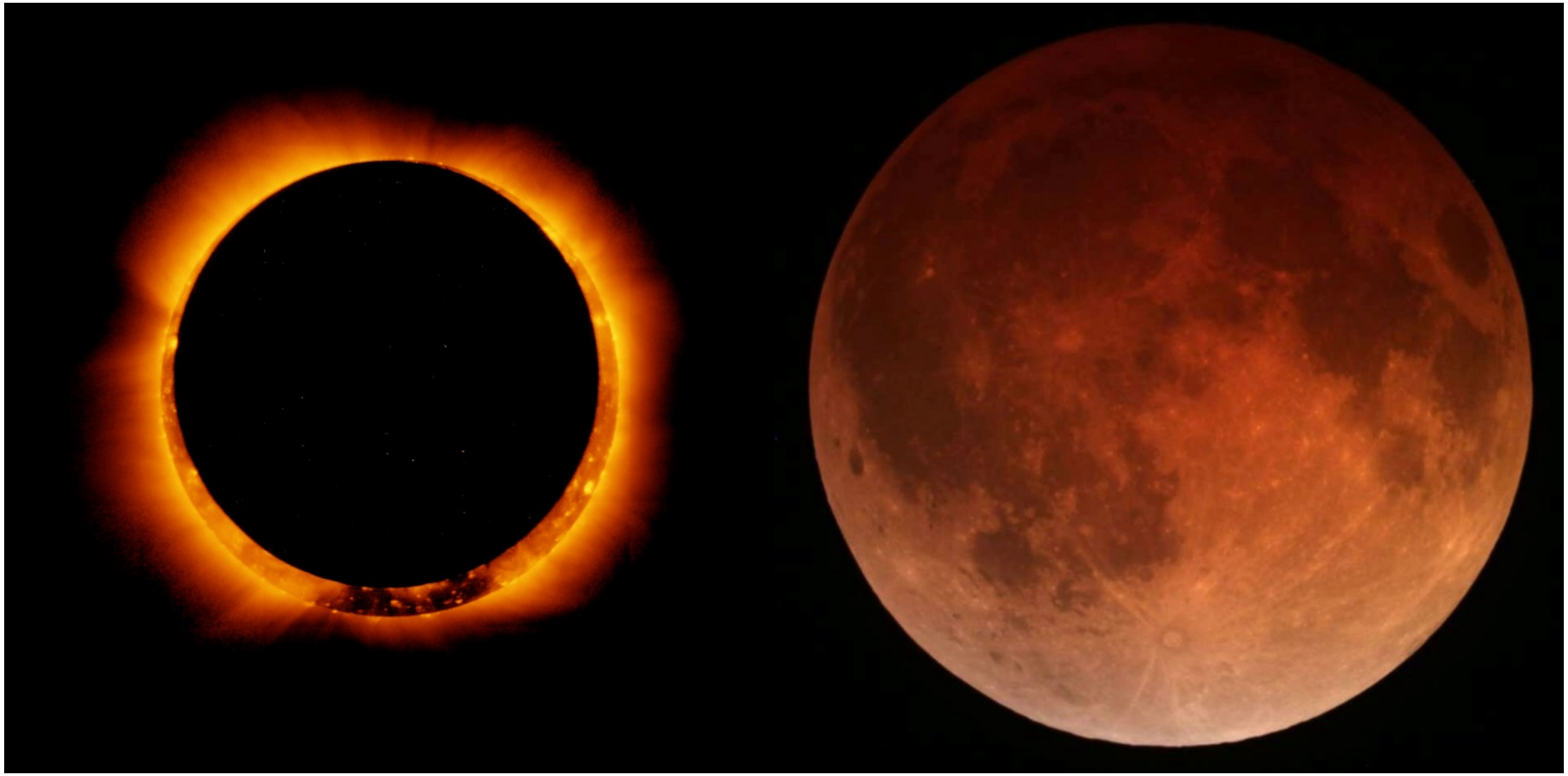

Image: NASA/Hinode/XRT

Image: Alfredo García Jr.
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Eclipses

A **solar eclipse** occurs when the Moon passes between the Sun and Earth, and the Moon fully or partially occults the Sun.

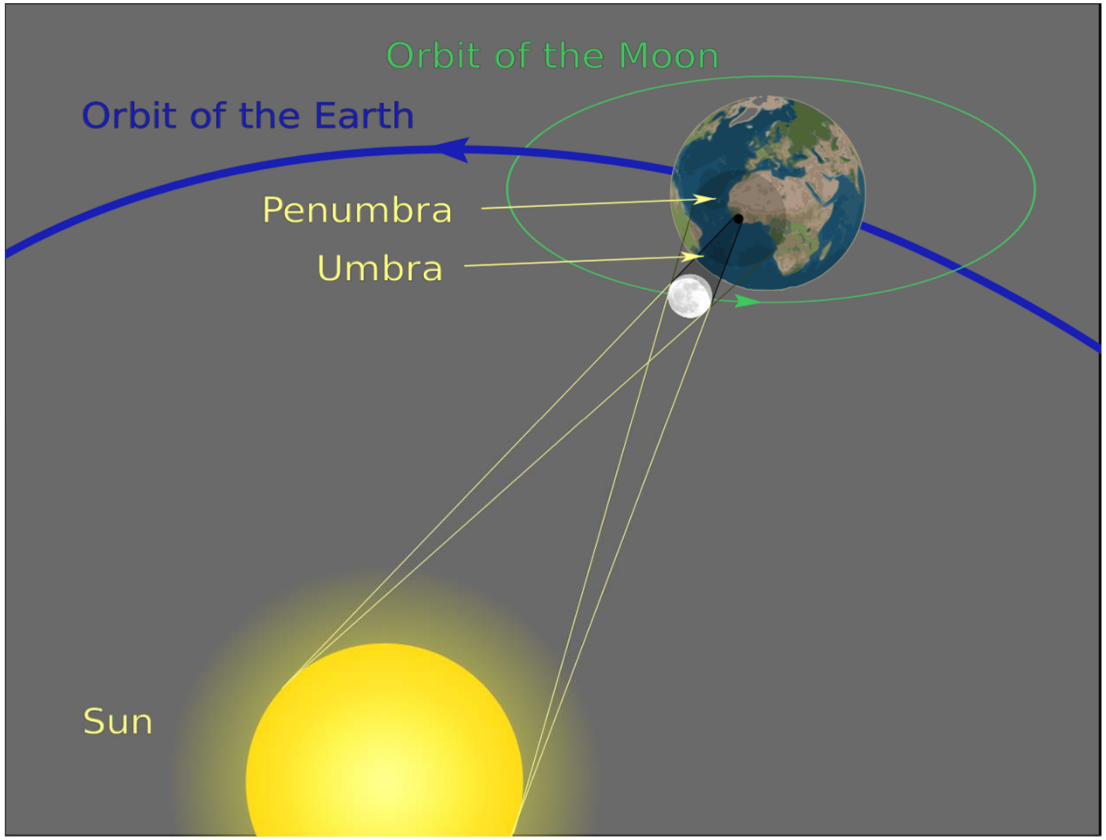


Image: Sagredo

Solar eclipses can only happen at ***New Moon***.

Astronomical observations

Eclipses

The Sun and the Moon as seen from Earth seem to have approximately the same size, and thus the Moon can completely block the Sun during total solar eclipses.

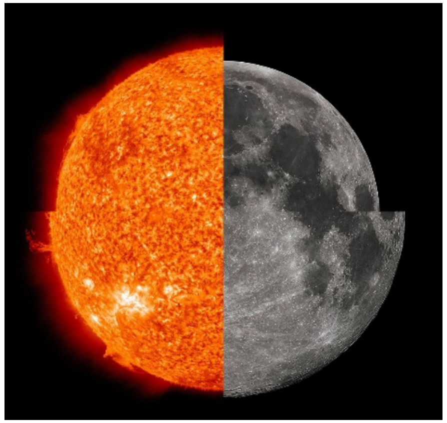


Image: Tdadamemd
CC BY-SA 4.0

This is because the Sun's diameter is about 400 times the Moon's diameter and the Sun's distance from Earth is about 400 times the Moon's distance.

	SUN	MOON
Diameter	1 392 684 km	3 474 km
Distance from Earth	150 000 000 km	385 000 km

Eclipses

A **lunar eclipse** occurs when the Moon passes directly behind Earth into its shadow.

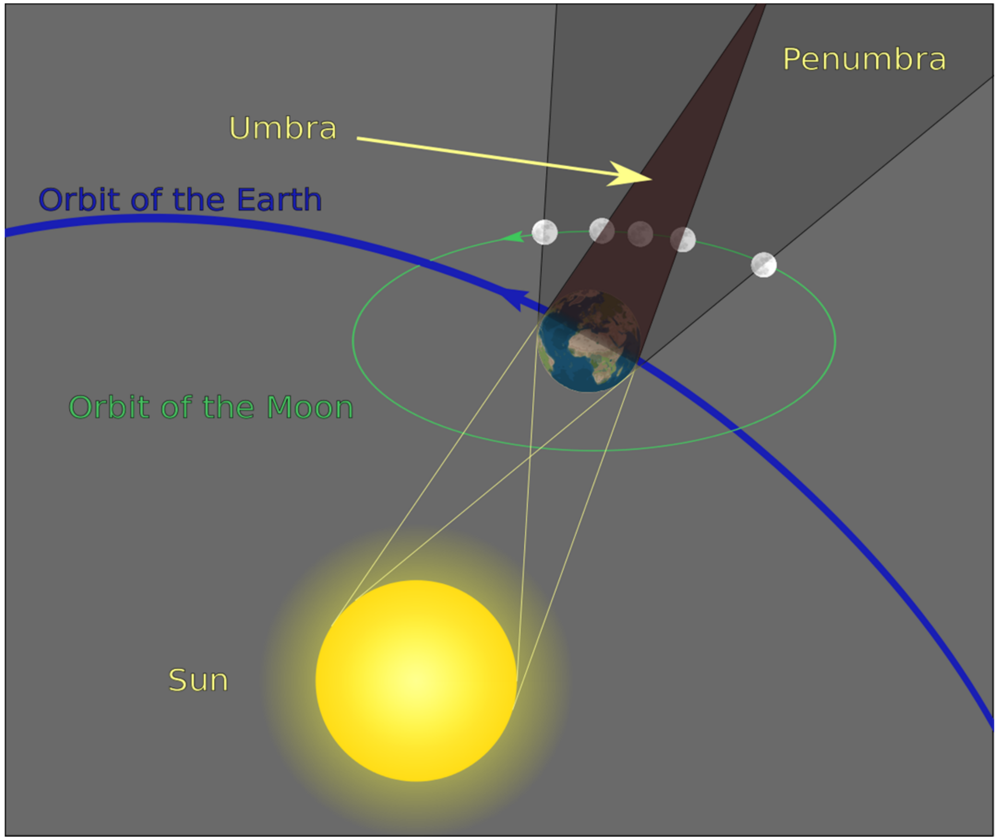


Image: Sagredo

Lunar eclipses can only happen at ***Full Moon***.

Astronomical observations

Eclipses

Why don’t we have eclipses every month?

Because the plane of the Moon's orbit is tilted 5.2° with respect to the plane of the Earth's orbit around the Sun.

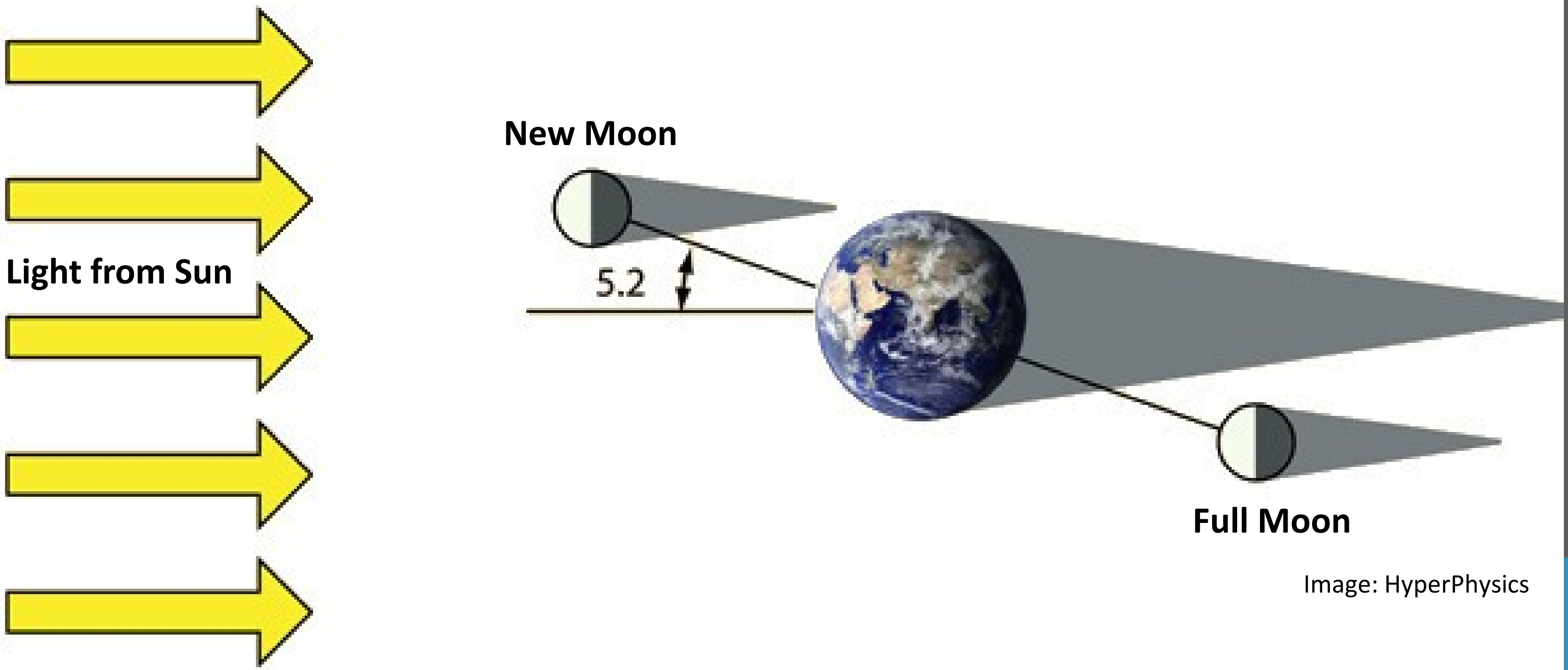


Image: HyperPhysics

Astronomical observations

Eclipses

Why don't we have eclipses every month?

Eclipses only occur at the points at which the Moon's orbit passes through the plane of the Earth's orbit around the Sun.

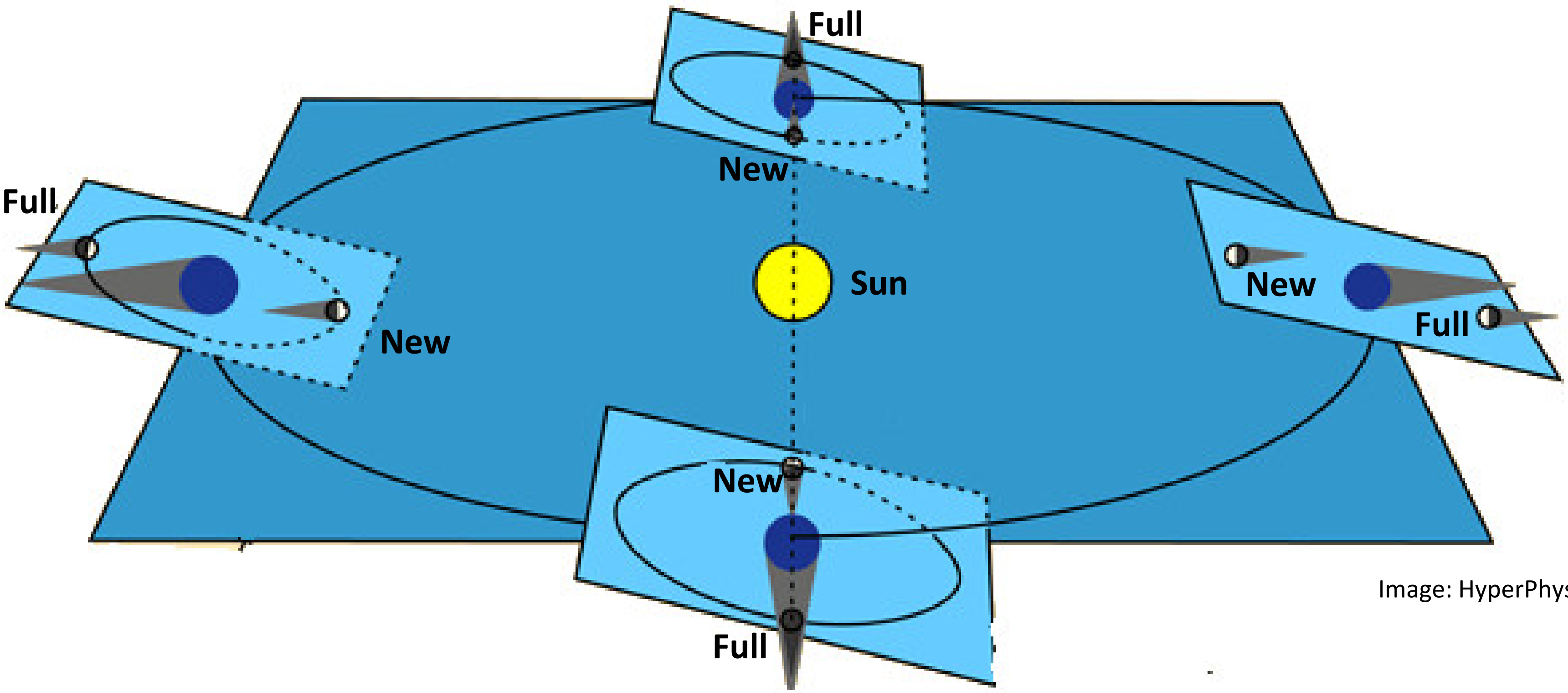


Image: HyperPhysics

Astronomical observations

Earth and Sun

Earth rotates around its own axis (**Earth's rotation**) from west to east.

Earth makes a complete turn every 23 hours, 56 minutes and 4 seconds (~**24 hours**).

Earth's rotation results in the alternation between **day** and **night**.

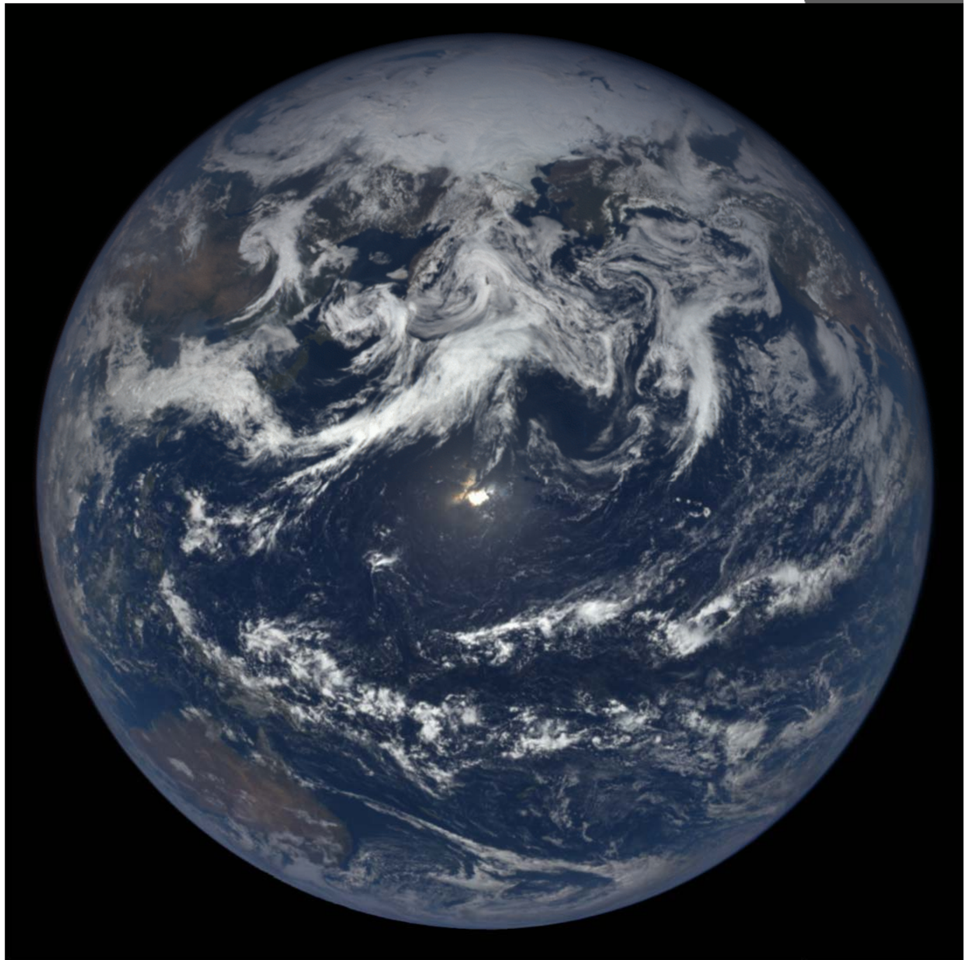
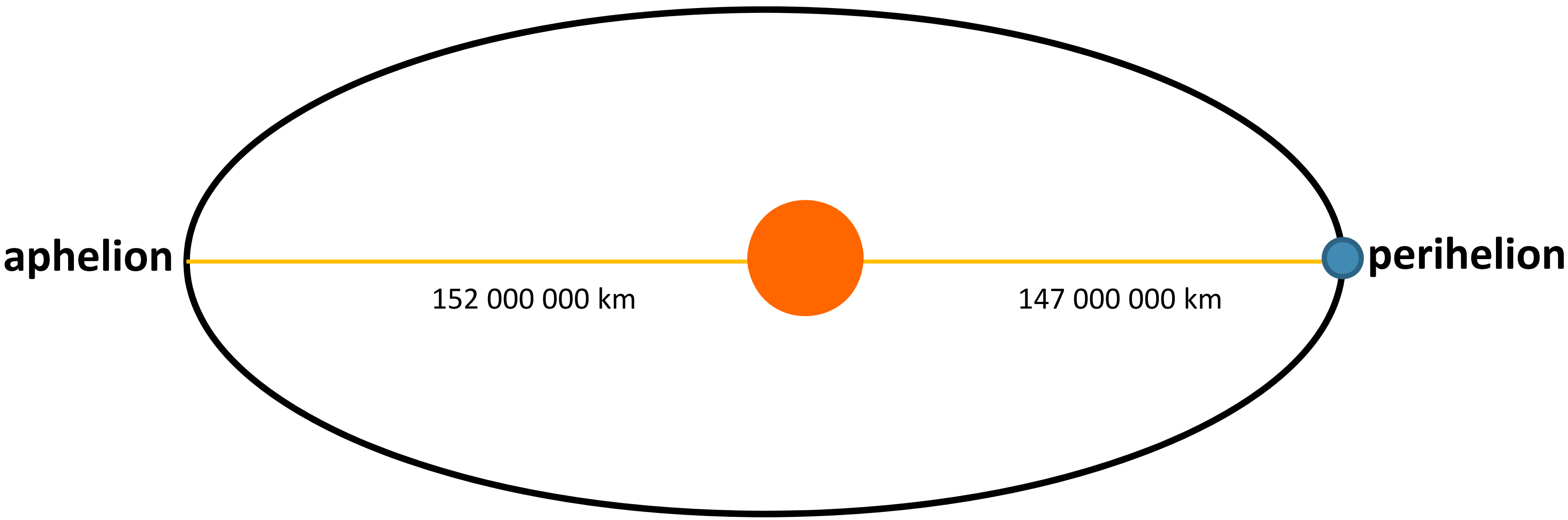


Image: NASA/EPIC

Astronomical observations

Earth and Sun

Earth is moving around the Sun in an elliptical orbit (**Earth's orbit**). A complete orbit occurs every 365 days, 5 hours, 48 minutes and 45.16 seconds (~**365 days**).



Aphelion: point in a planet's orbit where it is farthest from the Sun.

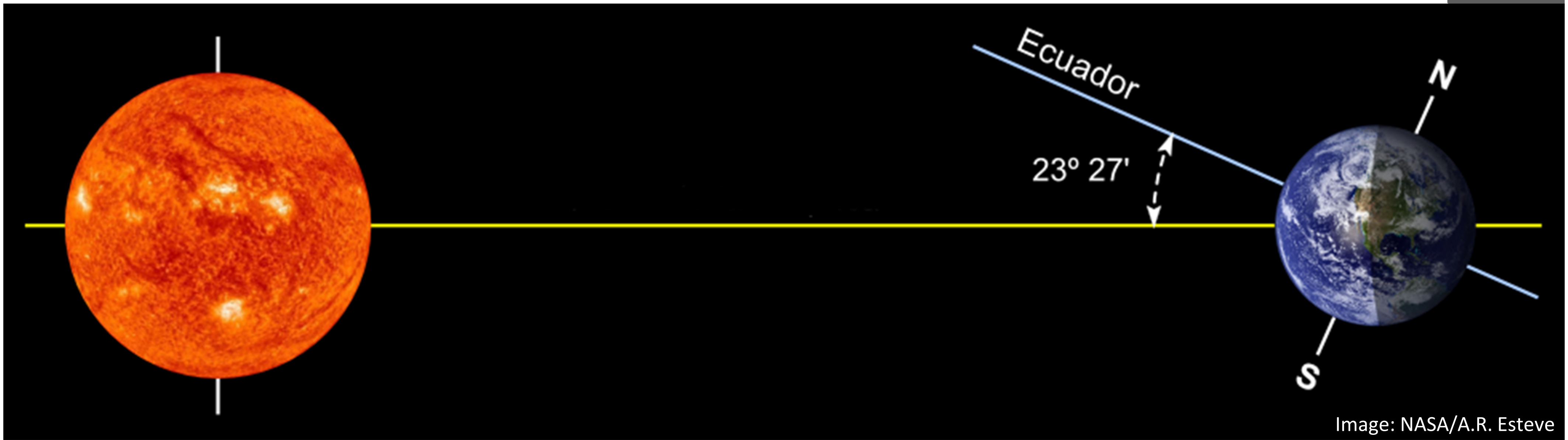
Perihelion: point in a planet's orbit where it is nearest to the Sun.

The **average distance from Earth to the Sun** is **150 000 000 km**.

Astronomical observations

Earth and Sun

Earth's rotation axis is tilted **23.5°** to the plane of Earth's orbit around the sun.



This inclination of Earth's rotation axis relative to the plane of Earth's orbit around the Sun causes the **seasons**.

Astronomical observations

Earth and Sun

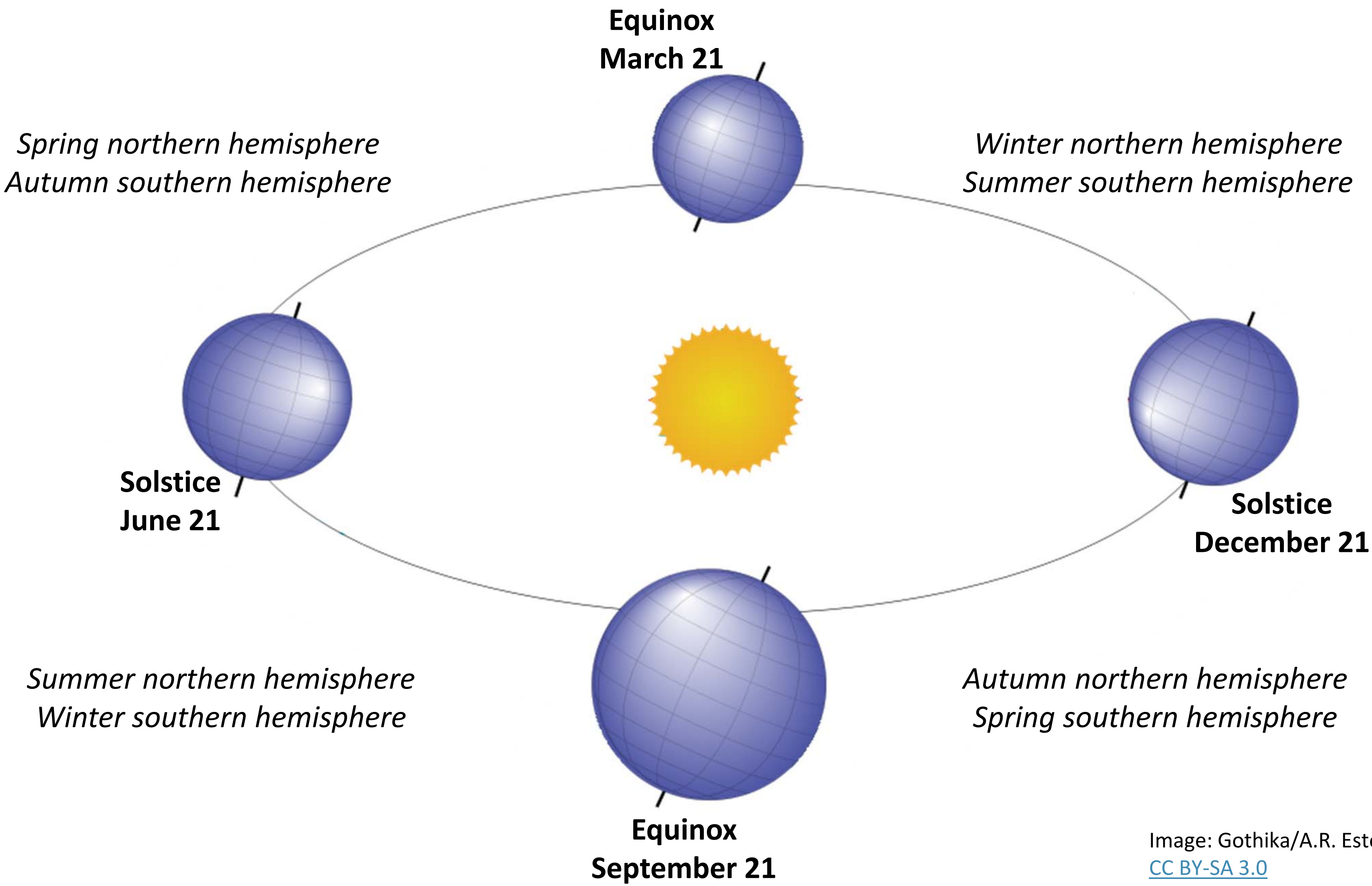


Image: Gothika/A.R. Esteve
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Astronomical observations

Earth and Sun

Since Earth's axis is always tilted in the same direction, Earth's northern and southern hemispheres receive different amounts of sunlight depending on the time of year.

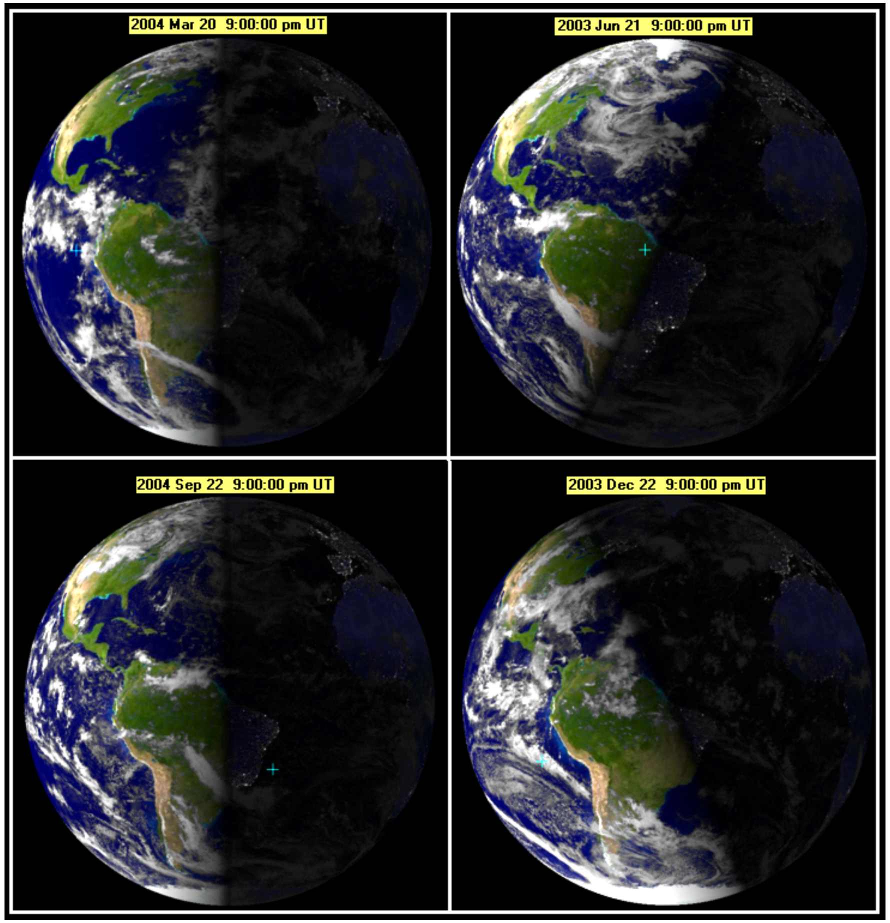

Image: Tom Ruen, Full Sky Observatory

Astronomical observations

Earth and Sun

- During **spring** and **summer**, the **northern hemisphere** is leaning towards the Sun, so the **Sun's rays** reach it more **perpendicularly**, focusing the solar radiation on a smaller area and producing an **increase in temperatures**. June 21 (**summer solstice**) is when the Sun reaches its highest apparent height in the sky.
- During **autumn** and **winter**, the **northern hemisphere** is not leaning towards the Sun, so the **Sun's rays** reach it more **obliquely**, spreading out the solar radiation on a larger area and producing a **decrease in temperatures**. 21 December (**winter solstice**) is when the Sun reaches its lowest apparent height in the sky.

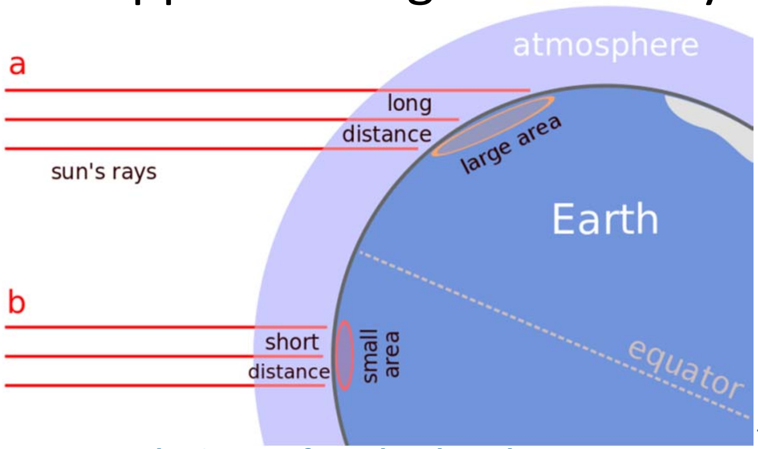

Image: Peter Halasz
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Astronomical observations

<u>Earth and Sun</u>

In the **northern hemisphere** ...

- In the **spring and autumnal equinoxes**, the Sun rises exactly in the **east (E)** and sets exactly in the west **(W)**. The length of day and night is the same.

- In the **summer solstice**, the Sun rises in the **northeast (NE)** and sets in the **northwest (NW)**, so it is visible during many more hours. The length of daytime is maximum.

- In the **winter solstice**, the Sun rises in the **southeast (SE)** and sets in the **southwest (SW)**, so it is visible during many fewer hours. The length of daytime is minimum.

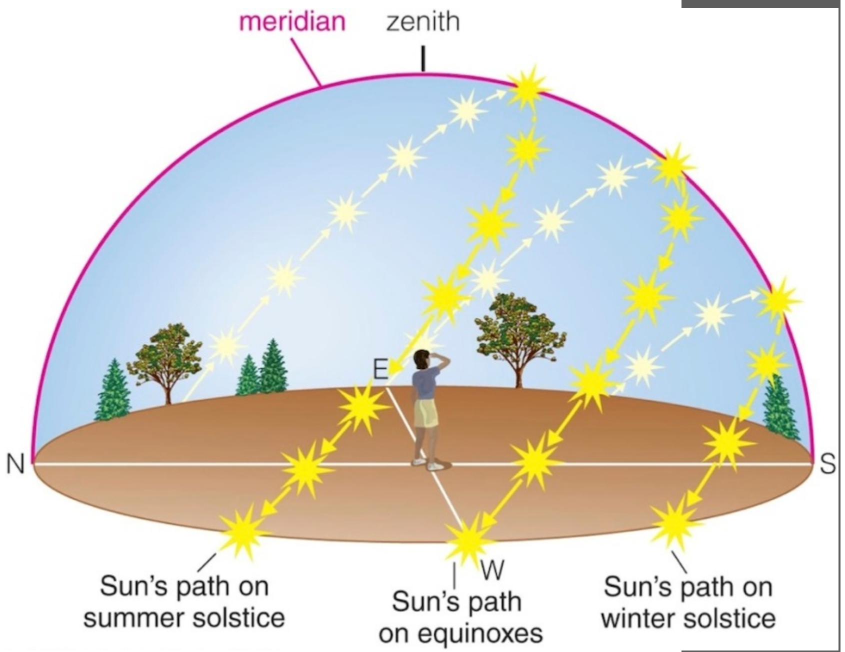

Image: Pearson Education

Astronomical observations

The uses of astronomy

- Around 2000 BC, the **Egyptians** fixed their yearly calendar observing a star named **Sothis**, which made its first appearance in the sky each year just before the annual Nile flooding.

Image: The Yorck Project

- **Mesopotamians** followed a **lunar calendar** in which the year had 360 days and was divided into 12 months of 30 days. The day was divided into 12 double hours. The hours were divided into sexagesimal (base 60) minutes and seconds.

Astronomical observations

The uses of astronomy

- Some **indigenous peoples in North America** built stone monuments, known as **medicine wheels**, marking the summer solstice sunrise or the rising of the other bright stars.
- The **Maya people** developed very precise **calendars** based on the Sun, Moon, and Venus. They also built an astronomical observatory in the city of **Chichén Itzá**.

Medicine Wheel
(Bighorn National Forest, Wyoming, EE.UU.)
Image: U.S. Forest Service Photo

El Caracol, Chichén Itzá (Yucatán, México)
Image: Daniel Schwen
CC BY-SA 4.0

Astronomical observations

The uses of astronomy: orientation

By day, we can use the **Sun** to orientate ourselves because the Sun rises in the east and sets in the west. Besides, the Sun at noon indicates the south in the northern hemisphere and the north in the southern hemisphere.

Image: Danilo Pivato/www.danilopivato.com

Astronomical observations

The uses of astronomy: orientation

At night, we can also use the **stars** to orientate ourselves:

- the star **Polaris** (a.k.a. ***North Star***, at the end of the tail of Ursa Minor) always indicates the north in the northern hemisphere.
- the **Crux** constellation (a.k.a. ***The Southern Cross***) always indicates the south in the southern hemisphere,.

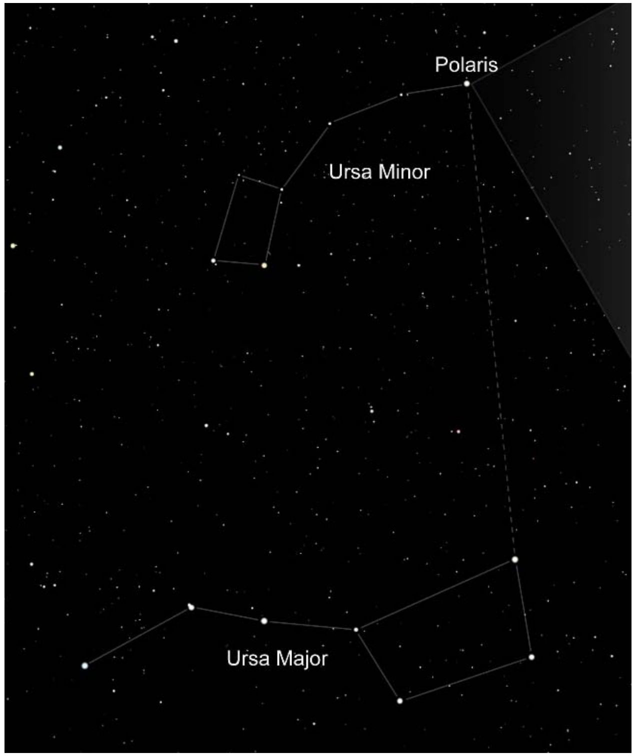

Image: NASA/HST

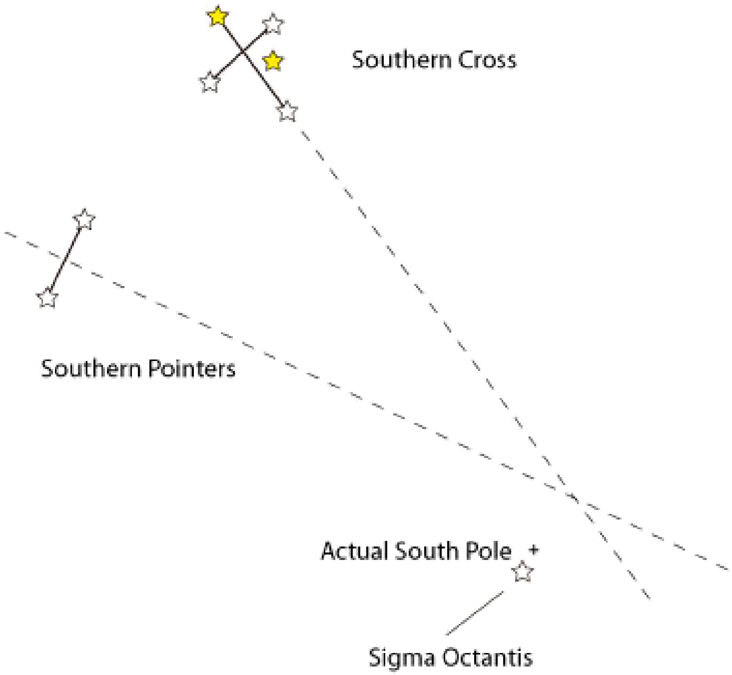

Image: Micke (usurped) at English Wikipedia
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Astronomical observations

The uses of astronomy: sundial

Sundials have been used to measure **time** since ancient times (Egyptians, Greeks, Romans ...).

These devices use the shadow cast by a **gnomon** (Greek for *'one that knows or examines'*) on a surface marked with lines that indicate the time of day by the apparent position of the Sun in the sky.

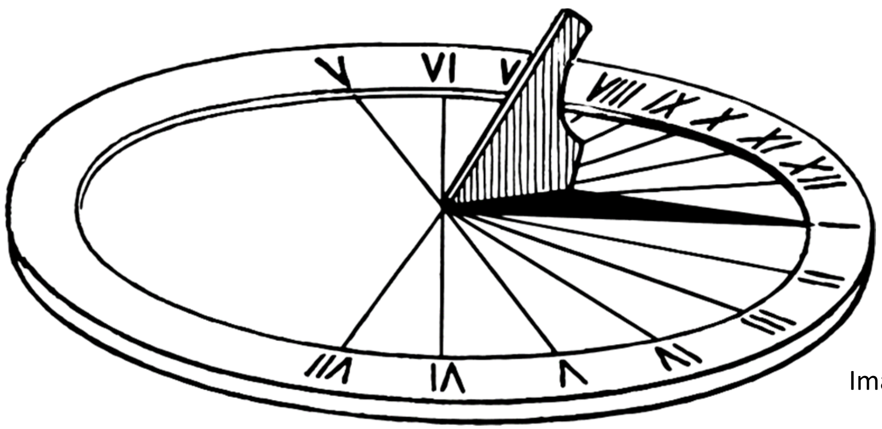

Image: Pearson Scott Foresman

Astronomical observations

The uses of astronomy: calendars

A **calendar** (from Latin *'calendae'*, which was the first day of each month in the Roman calendar) is a system to organise time for social, religious, commercial, or administrative purposes. This is done by giving names to periods of time: ***days***, ***weeks***, ***months*** and ***years***.

These time periods are usually based on solar or lunar cycles.

Image: Dafne Cholet
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Astronomical observations

<u>The uses of astronomy: calendars</u>

The **Julian calendar** was introduced by Julius Caesar in 46 BC.

- The year had **365 days** divided into 12 months with 30 or 31 days.
- The year started in spring, in the month **Martius** (named for Mars, god of war).
- The months of the year are: ***Martius*** (named for Mars, god of war), ***Aprilis*** (named for the Latin verb *'aperio'*, which means *'to open'*), ***Maius*** (named for Maia, goddess of fertility), ***Junius*** (named for Juno, goddess of women and marriage), ***Julius*** (in honor of Julius Caesar), ***Augustus*** (in honor of the first Roman emperor, Augustus), ***September***, ***October***, ***November***, ***December***, ***Januarius*** (named for Janus, god of beginnings and transitions), and ***Februarius*** (named for *Februa*, the Roman festival of ritual purification).
- Since a year has actually 365.25 days, a **leap day** was added every 4 years.

The uses of astronomy: calendars

Since a year has actually 365.242189 days (365 days, 5 hours, 48 minutes and 45.16 seconds), a **shift of 3 days** appears **every 400 years**.

The **Gregorian calendar** was introduced by Pope Gregory XIII in 1582.

- Thursday ***4 October 1582*** (in the Julian calendar) is followed by Friday ***15 October 1582*** (in the Gregorian calendar). The 10 days that 'disappear' were already counted in the Julian calendar.
- The Gregorian calendar establishes that every year that is **exactly divisible by four** is a **leap year**, except for years that are **exactly divisible by 100** (1700, 1800, 1900 … are not leap years), but these centurial years are leap years if they are **exactly divisible by 400** (1600, 2000, 2400 … are leap years).

Astronomical observations

The uses of astronomy: calendars

In the **Gregorian calendar**,

- there are **common years** (365 days) and **leap years** (366 days).
- months have 30 or 31 days, except February, which has 28 days (29 days in leap years).

Thirty days hath September,
April, June, and November.
All the rest have 31,
Except for February all alone,
It has 28 each year,
but 29 each leap year.

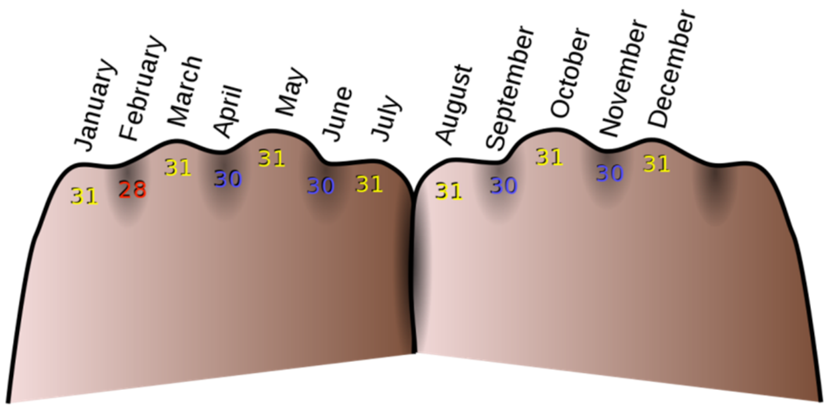

Image: Tijmen Stam/IIVQ
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Astronomical observations

The uses of astronomy: astronomy vs. astrology

Given the importance that astronomy had on agriculture, navigation, etc., people began to think that the astronomical objects also had some influence on people's lives (**astrology**).

For centuries, there was no real separation between astronomy and astrology (many astronomers were also astrologers: such as Ptolemy, Galileo, and Johannes Kepler).

Image: Zachariel
CC0

Astronomical observations

The uses of astronomy: astronomy vs. astrology

Astronomy and astrology have been considered completely separate disciplines since the 18th century (Age of Enlightenment).

Astronomy is a **science** that studies celestial objects (planets, stars, galaxies, etc.). Astronomers base their studies on research and observation.

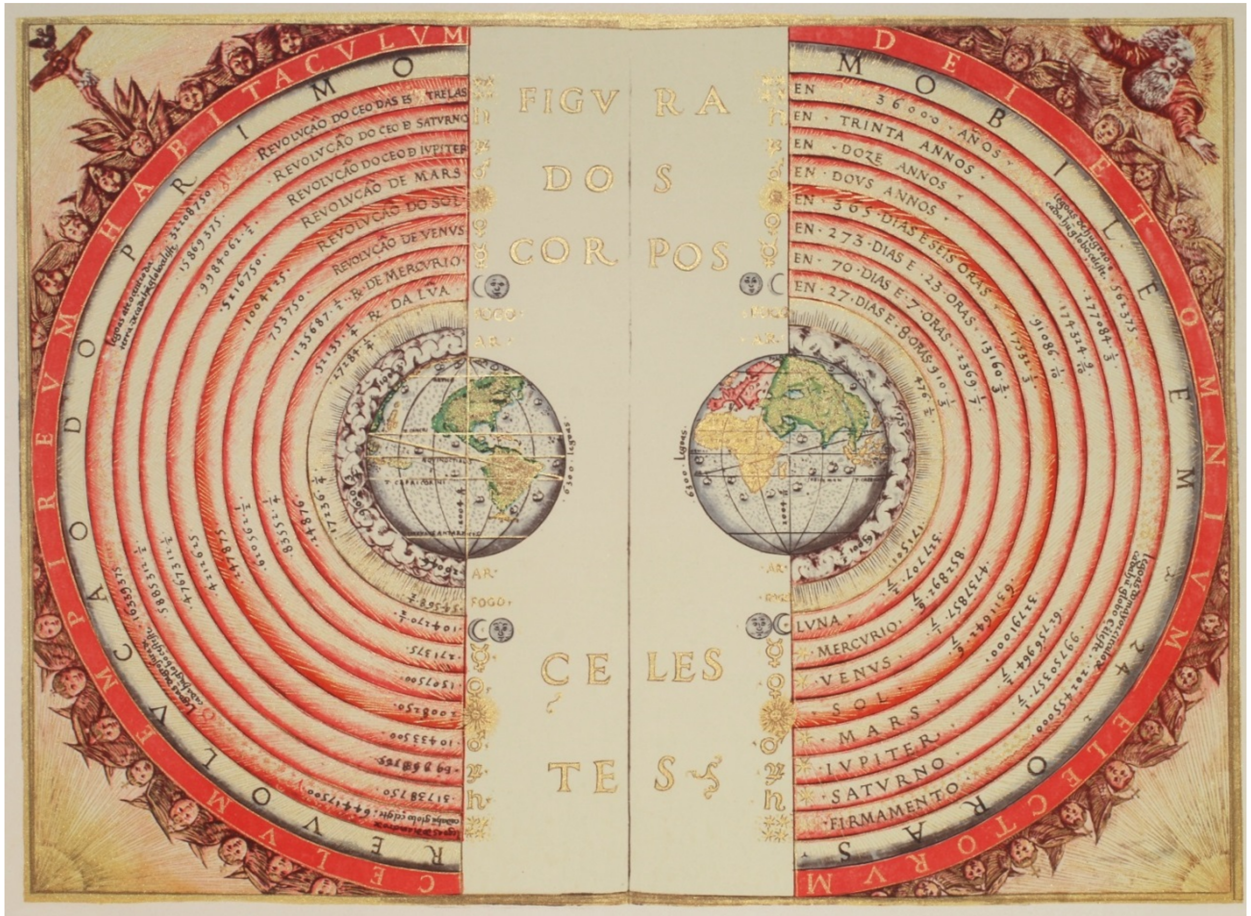
Astrology is a belief system (or **pseudoscience**) that holds that the positioning of the stars and planets affect the way events occur on Earth. However,

- different horoscopes predict different things
- predictions are ambiguous
- twins (born under the same sign) have different lives

Models of the universe: geocentrism and heliocentrism

Geocentric model

Geocentrism places **Earth** at the **center of the universe**, with all celestial bodies revolving around it.



Bartolomeu Velho, 1568
Bibliothèque Nationale, Paris

Models of the universe: geocentrism and heliocentrism

Geocentric model

Early astronomers proposed a **celestial model** in which the stars were fixed on a spherical surface that revolved around Earth.

They knew of seven celestial objects, visible to the naked eye, that revolved around Earth and whose positions changed relative to the fixed stars:

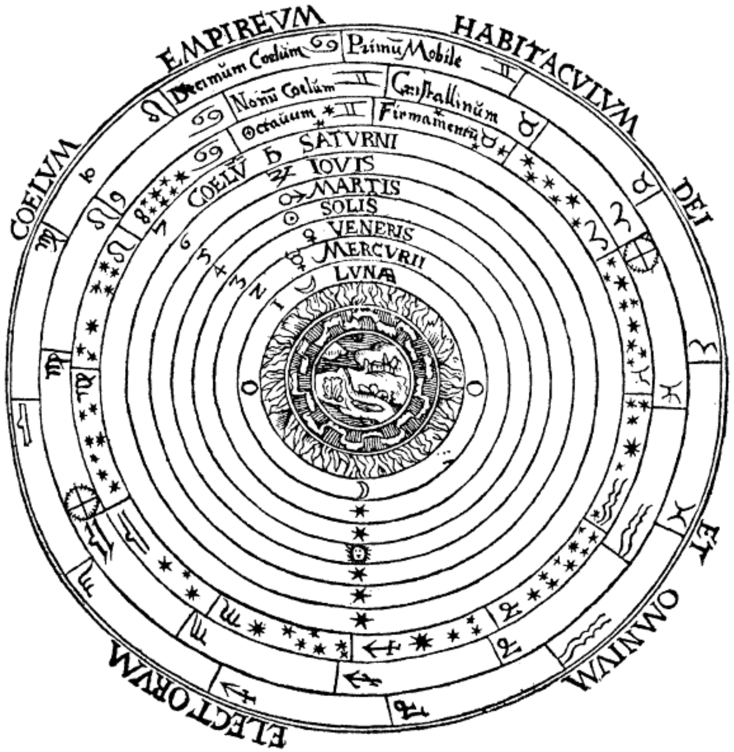
- the **Sun**
- the **Moon**
- the planets (Greek for *'wandering star'*) **Mercury**, **Venus**, **Mars**, **Jupiter** and **Saturn**.

Models of the universe: geocentrism and heliocentrism

Geocentric model

Aristotle (384–322 BC) proposed the following **geocentric model**:

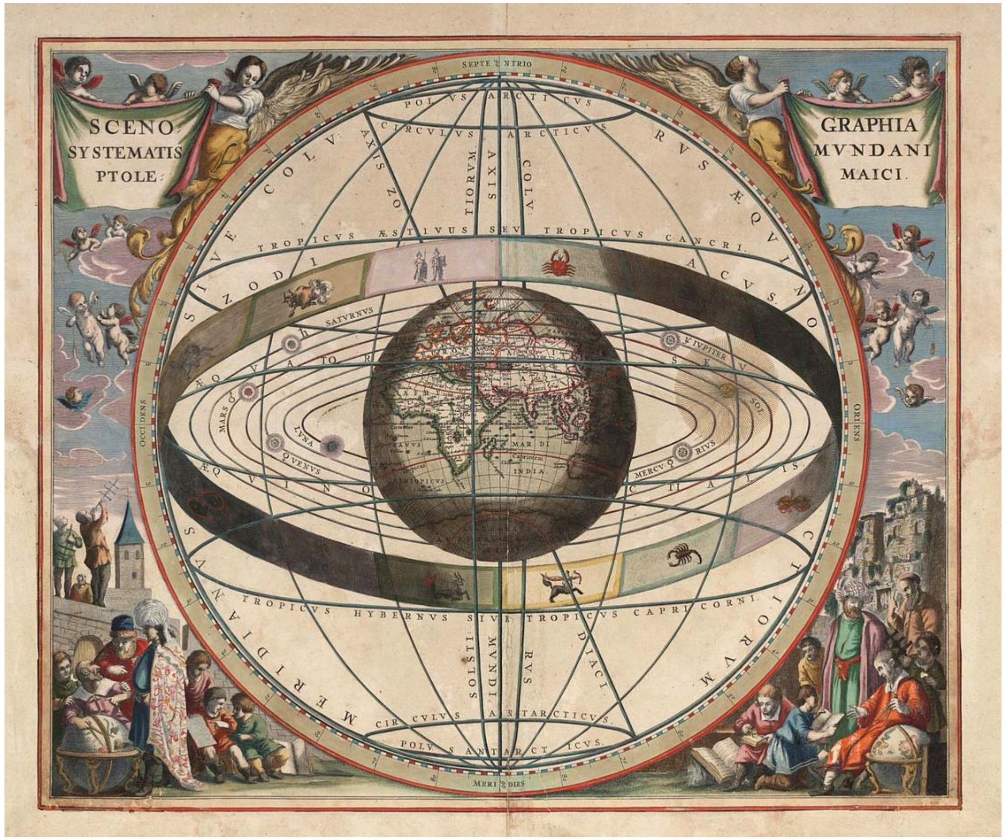
- **Earth**, unmoving, is the **centre of the universe**.
- The universe is composed of eight **concentric spheres**, which contain the Sun, the Moon, the stars and planets, revolving **around the Earth**.
- There is a ***sublunary world*** (imperfect) and a ***supralunary world*** (perfect).
- Earth is composed of four elements: **earth**, **air**, **fire** and **water**, while the sky is composed of a single element called **aether**.



Models of the universe: geocentrism and heliocentrism

Geocentric model

The ***Almagest*** is an astronomical treatise written by **Ptolomy** (100–170) which contains the most complete **star catalog** of that time, and in which the **geocentric model** and the apparent motions of the stars and planets are described.



Johannes van Loon, ca. 1611-1686
(National Library of Australia)

Models of the universe: geocentrism and heliocentrism

Geocentric model

Aristotle's **geocentric model** was kept during nearly 20 centuries for several reasons:

- It was consistent with **common sense**.
- It agreed with **Christianity**, which considers heaven as the realm of divine perfection, while Earth is the centre of everything and an imperfect place (sin).
- Its stratified view of the universe was an example of the **social hierarchy**: ‘inferior’ beings (slaves, women, peasants) and ‘superior’ beings (clergy, nobles).

Psalter world map, ca. 1260

Models of the universe: geocentrism and heliocentrism

<u>Geocentric model</u>

However, **geocentrism** was unable to explain some astronomical observations.

- The rising and setting points of the **Sun** and **Moon** change throughout the year.

- Some **stars** and **planets** ‘disappear’ for months.

- The planets sometimes seem to move in a direction opposite to that of the stars (**apparent retrograde motion**).

Models of the universe: geocentrism and heliocentrism

Geocentric model

As seen from Earth, the planets sometimes seem to move in a direction opposite to that of the stars (**apparent retrograde motion**).

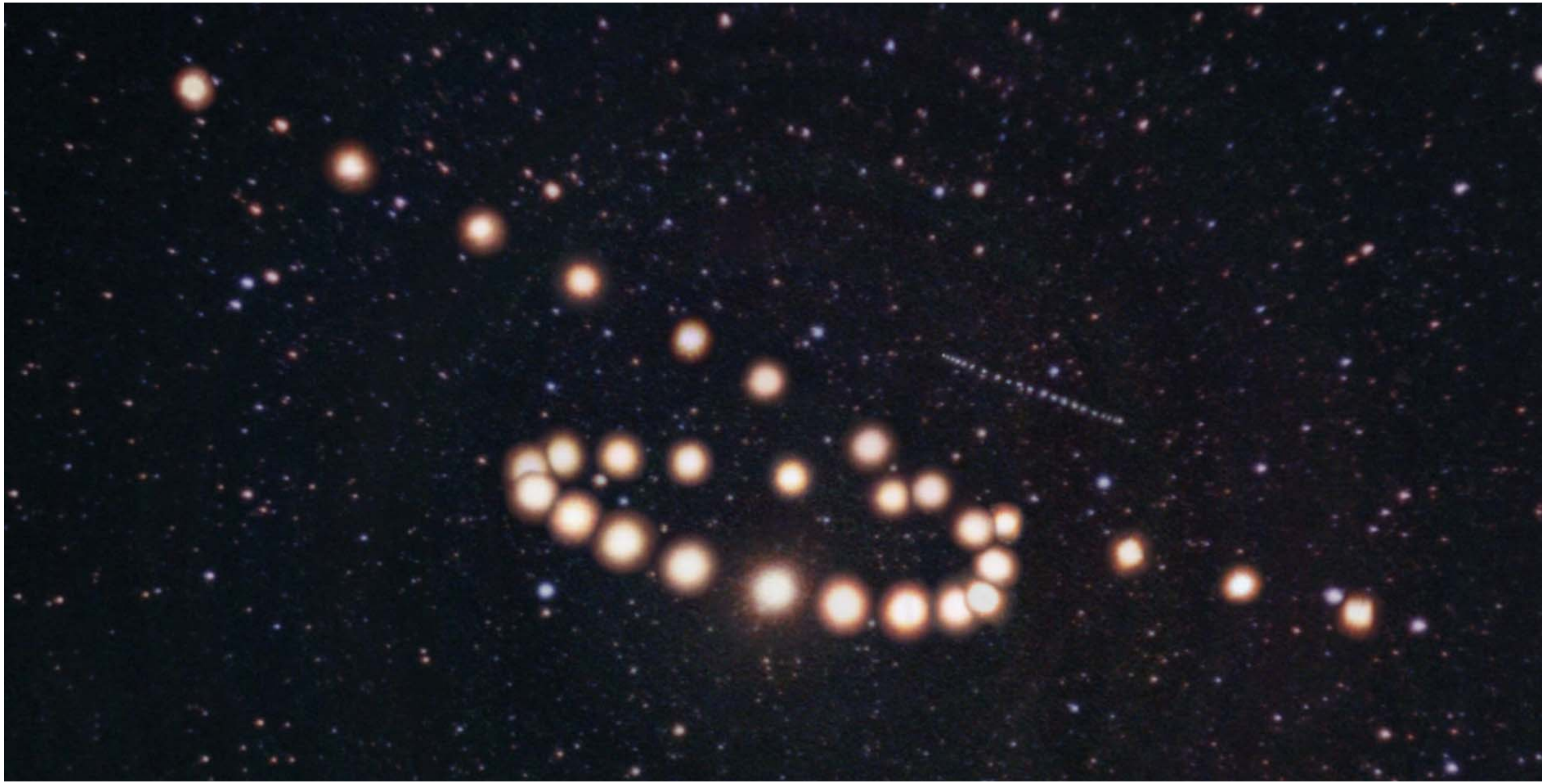


Image: Tunc Tezel

Models of the universe: geocentrism and heliocentrism

Geocentric model

Ptolomy's explanation of the **apparent retrograde motion** of the planets was to assume that the planets move in a small circle (**epicycle**), which in turn moves along a larger circle (**deferent**).

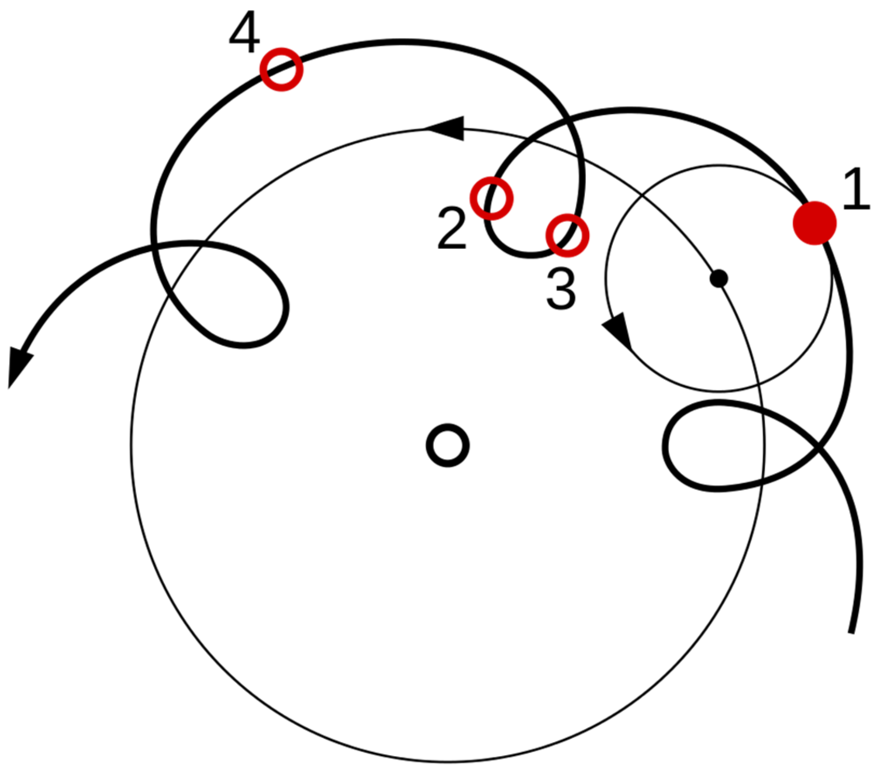


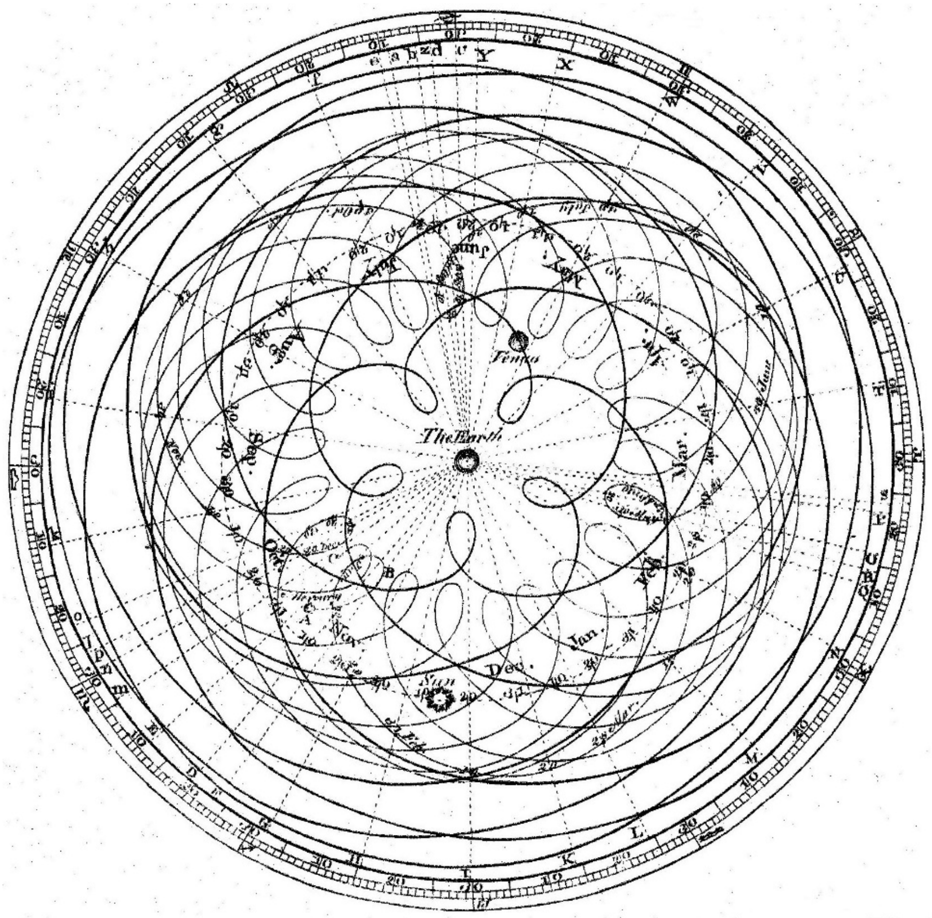
Image: MLWatts

http://astro.unl.edu/naap/ssm/animations/ptolemaic.html

Models of the universe: geocentrism and heliocentrism

Geocentric model

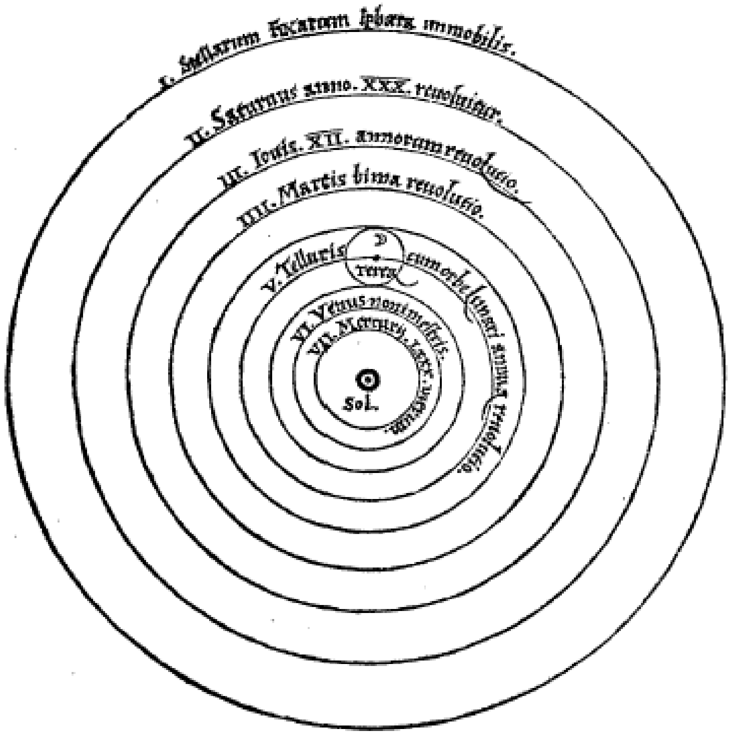
Geocentrism gave a very complicated explanation to the trajectory of celestial bodies.



Models of the universe: geocentrism and heliocentrism

<u>Heliocentric model</u>

Nicolaus Copernicus (1473–1543), in his book ***De revolutionibus orbium coelestium*** (*On the Revolutions of the Heavenly Spheres*) (1543), proposed the **heliocentric model** of the universe.



Heliocentrism places the **Sun** near the center of the universe, with Earth and the other planets revolving around it.

Models of the universe: geocentrism and heliocentrism

Heliocentric model

The main features of **Copernicus' heliocentric model** are:

- **Celestial motions** are **uniform**, **eternal**, and **circular** or composed of several circles (epicycles).
- The **center of the universe** is near the **Sun**.
- Revolving around the Sun are Mercury, Venus, Earth and the Moon, Mars, Jupiter and Saturn.
- The **stars** are celestial objects located far away which remain fixed and do not revolve around the Sun.
- The **distance** from **Earth** to the **Sun** is **small** compared to the distance to the **stars**.
- **Earth** has three **motions**: **daily rotation**, **annual revolution**, and **annual tilting of its axis**.
- The **apparent retrograde motion of the planets** is explained by the **Earth's motion**.

Models of the universe: geocentrism and heliocentrism

Heliocentric model

Copernicus's heliocentric model meant a **scientific revolution**, and its publication caused great controversy.

The main argument against heliocentrism was ideological, since it was considered that it contradicted the Bible.

Copernicus' book ***De revolutionibus orbium coelestium*** was included in the ***Index librorum prohibitorum Index*** (*Index of forbidden books*) of the Catholic Church in 1616.

Nevertheless, other astronomers questioned the geocentric model too, and helped demonstrate the validity of the heliocentric model.

Models of the universe: geocentrism and heliocentrism

Johannes Kepler

Johannes Kepler (1571-1630) used the data obtained by Danish astronomer ***Tycho Brahe*** (1546-1601) to help prove the heliocentric model.

Kepler formulated the **three laws of planetary motion**:

1. The orbits of the planets are ellipses, with the Sun at one focus.
2. The line joining the planet to the Sun sweeps out equal areas in equal intervals of time.
3. The orbital period of a planet increases with the average distance of the planet to the Sun.

These laws are more consistent with astronomical observations than the circular motion.

Models of the universe: geocentrism and heliocentrism

<u>Johannes Kepler</u>

First law: the orbits of the planets are ellipses, with the Sun at one focus.

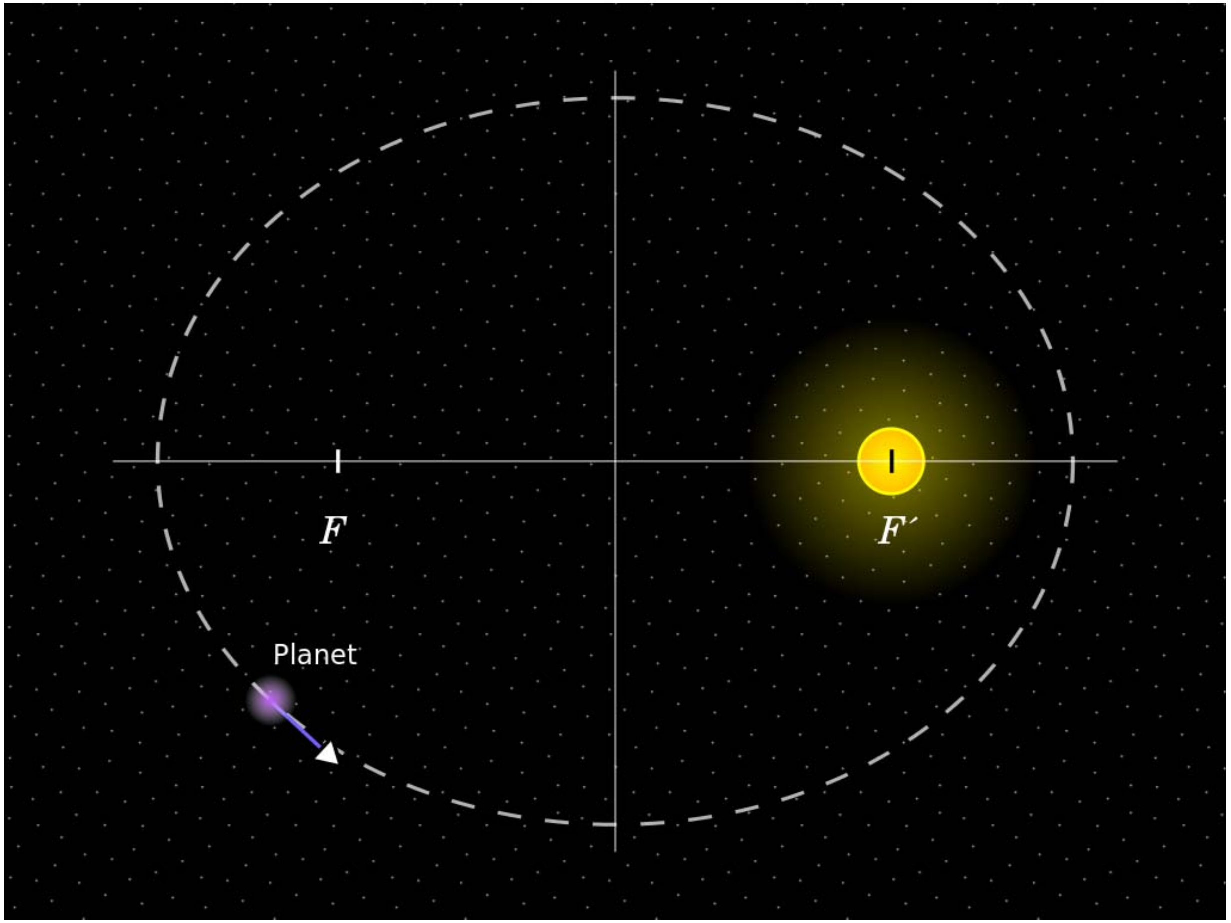


Image: Alberto Rodríguez
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Models of the universe: geocentrism and heliocentrism

<u>Johannes Kepler</u>

First law: the orbits of the planets are ellipses, with the Sun at one focus.

An **ellipse** is a curve on a plane surrounding two focal points such that the sum of the distances to the two focal points is constant for every point on the curve.

Focal points: F_1 and F_2

Major axis: AB

Minor axis: CD

Eccentricity: $e=F_1F_2/AB$

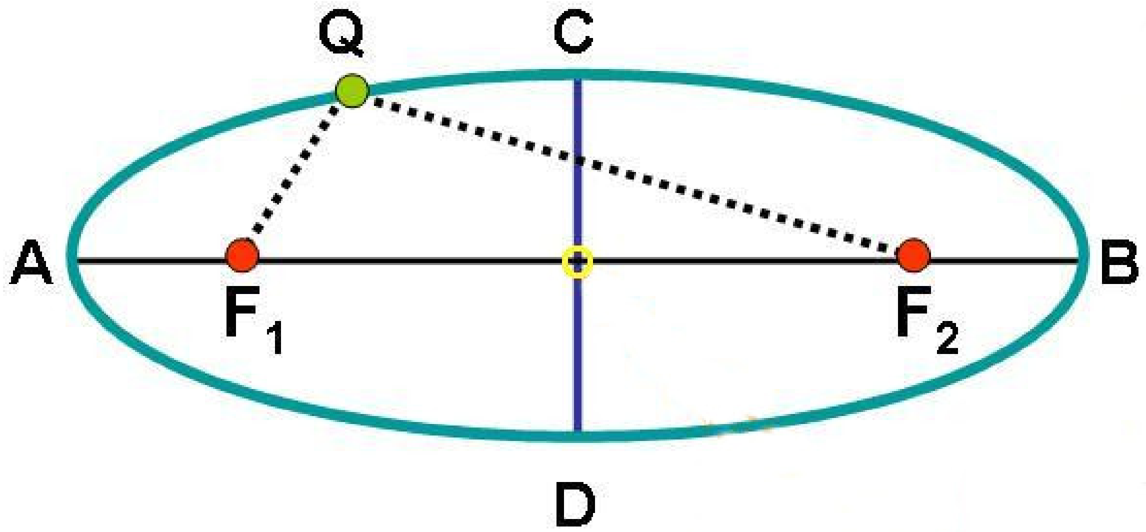
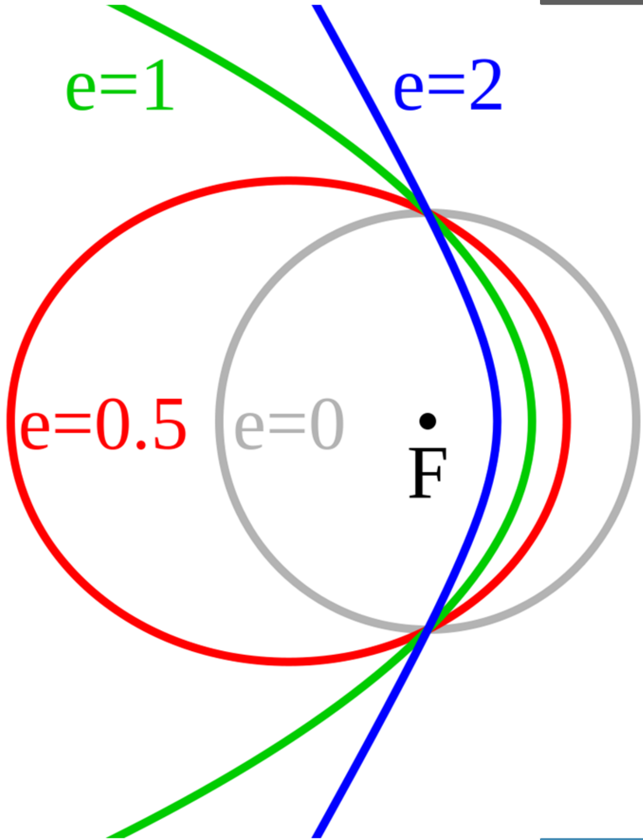


Image: Think Tank/A.R. Esteve

Models of the universe: geocentrism and heliocentrism

Johannes Kepler

First law: the orbits of the planets are ellipses, with the Sun at one focus.



Eccentricity (e) indicates the shape of the orbit:

e = 0	circle
0 < e < 1	ellipse
e = 1	parabola
e > 1	hyperbola

Image: ScottAlanHill
CC BY-SA 3.0

Johannes Kepler

First law: the orbits of the planets are ellipses, with the Sun at one focus.

The eccentricity of the planets of the solar system is very small:

Planet	eccentricity
Mercury	0.2060
Venus	0.0068
Earth	**0.0167**
Mars	0.0934
Jupiter	0.0485
Saturn	0.0556
Uranus	0.0472
Neptune	0.0086

Models of the universe: geocentrism and heliocentrism

<u>Johannes Kepler</u>

Second law: the line joining the planet to the Sun sweeps out equal areas in equal intervals of time.

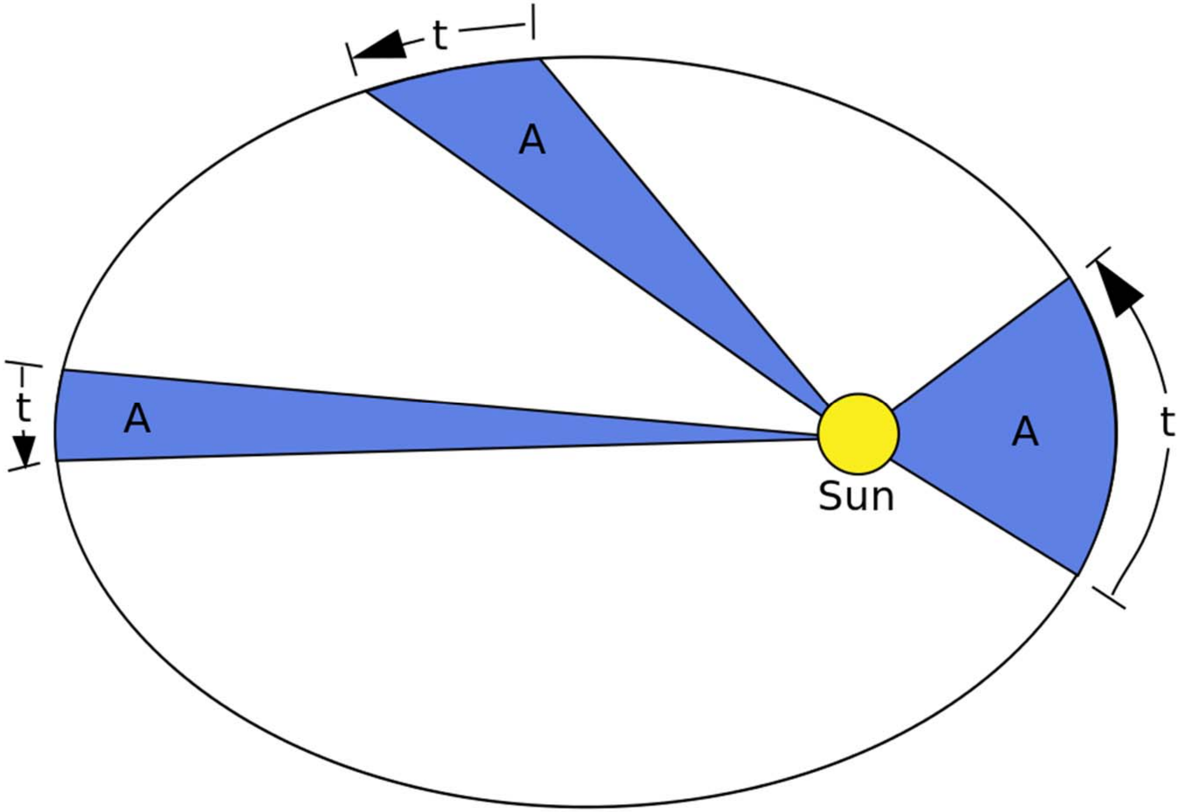


Image: RJHall/Talifero
[CC BY-SA 2.0 at](CC BY-SA 2.0 at)

Models of the universe: geocentrism and heliocentrism

Johannes Kepler

Second law: the line joining the planet to the Sun sweeps out equal areas in equal intervals of time.

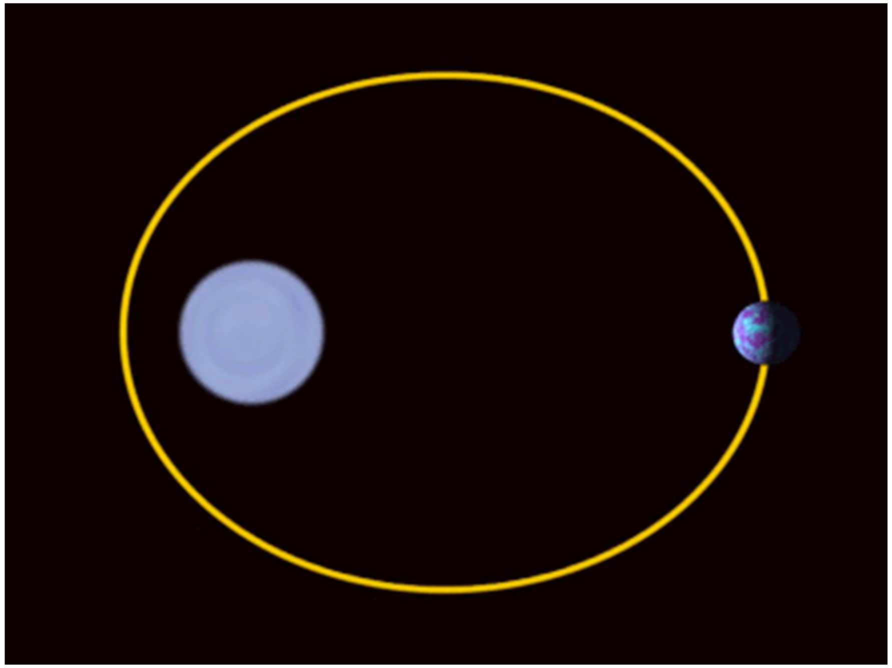


Image: WillowW
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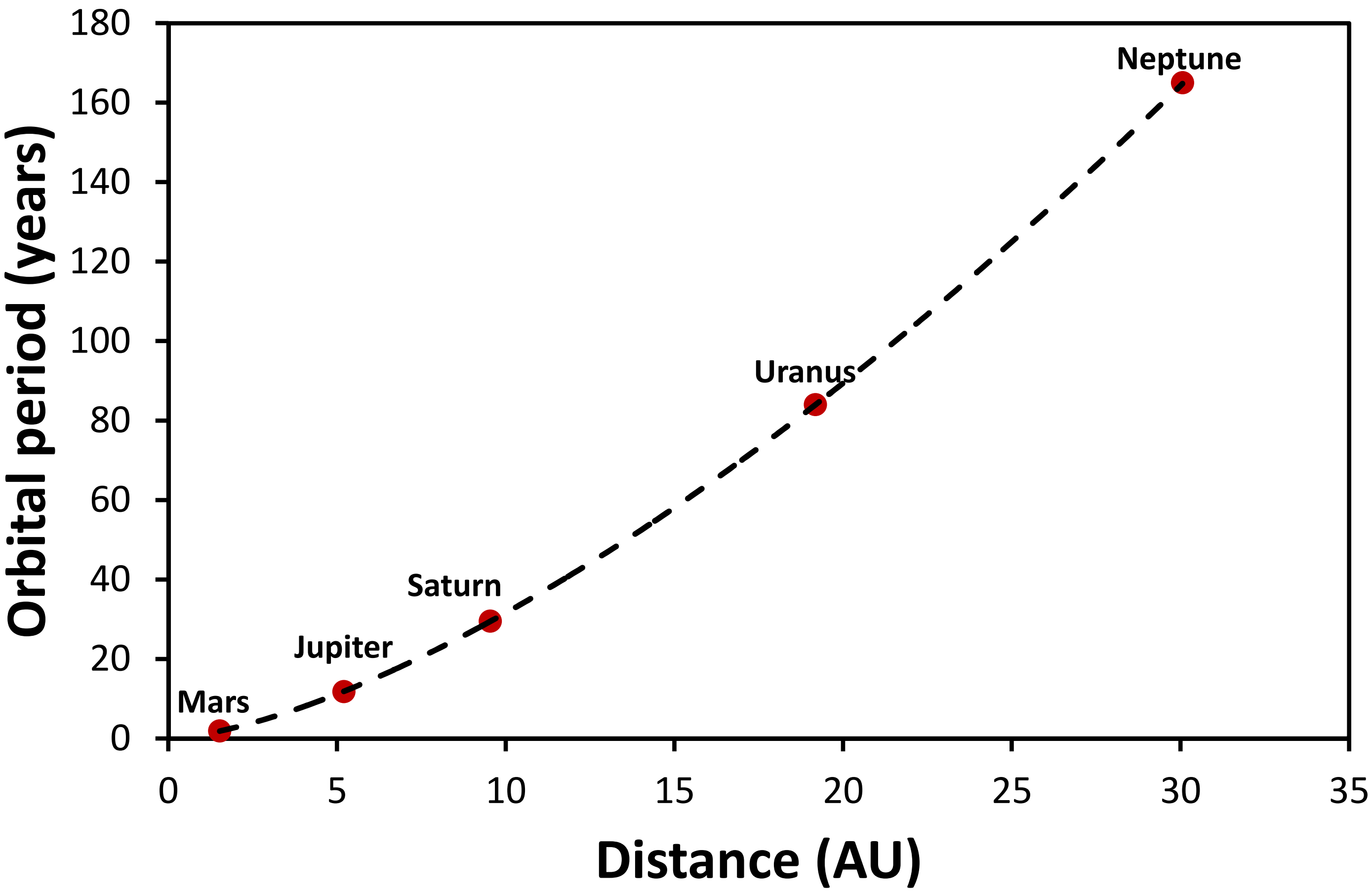
A planet will move faster when it is closer to the Sun!

(i.e., the planet does not move at a constant speed)

Models of the universe: geocentrism and heliocentrism

<u>**Johannes Kepler**</u>

Third law: the orbital period of a planet increases with the average distance of the planet to the Sun.



Models of the universe: geocentrism and heliocentrism

Johannes Kepler

Third law: the orbital period of a planet increases with the average distance of the planet to the Sun.

The square of the orbital period of a planet is proportional to the cube of the semi-major axis of its orbit.

$$\frac{T^2}{r^3} = k$$

Thus, the planets that are further from the Sun take longer to make a complete orbit, i.e., they move more slowly around the Sun.

https://youtu.be/gvSUPFZp7Yo

Models of the universe: geocentrism and heliocentrism

Johannes Kepler

Third law: the orbital period of a planet increases with the average distance of the planet to the Sun.

Planet	Orbital period (years)	Distance (AU)	T^2/r^3
Mercury	0.24	0.39	0.98
Venus	0.62	0.72	1.01
Earth	1.00	1.00	1.00
Mars	1.88	1.52	1.01
Jupiter	11.8	5.20	0.99
Saturn	29.5	9.54	1.00
Uranus	84	19.18	1.00
Neptune	165	30.06	1.00

Models of the universe: geocentrism and heliocentrism

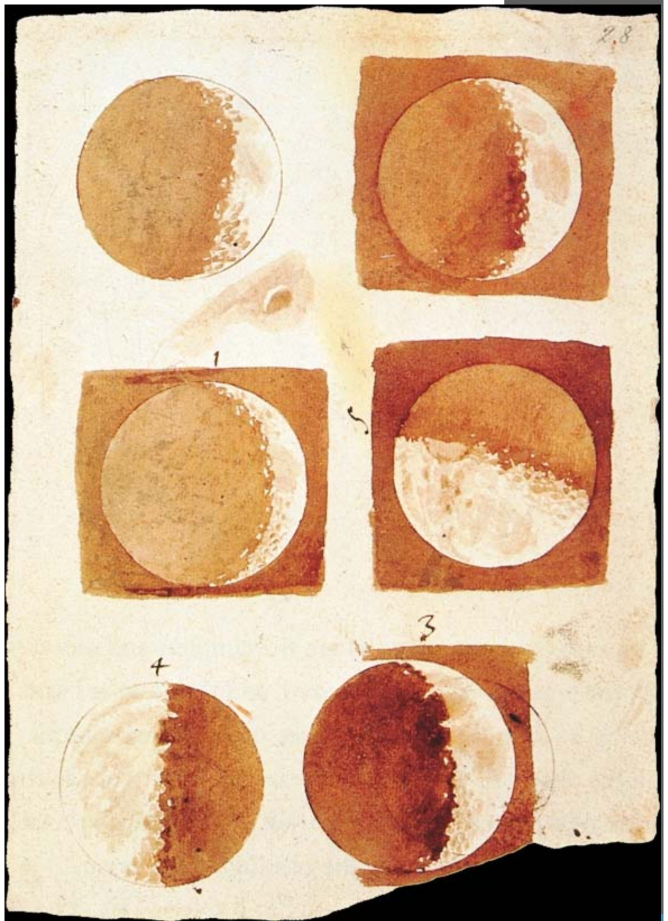
Galileo Galilei

Galileo Galilei (1564-1642) improved an invention which allowed the observation of distant objects, the **telescope**.

With the help of the telescope, Galileo discovered:

- craters and mountains on the Moon
- the four largest satellites of Jupiter
- the phases of Venus
- new stars

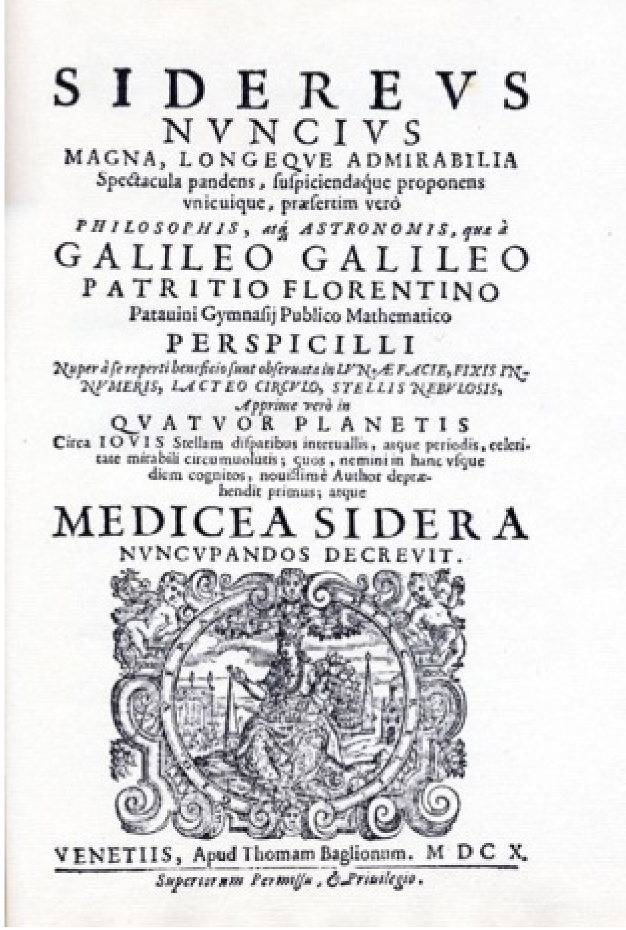
These observations contributed greatly to demonstrate the validity of the heliocentric model.



Models of the universe: geocentrism and heliocentrism

<u>Galileo Galilei</u>

In 1610 Galileo published the book ***Sidereus Nuncius*** (*The Starry Messenger*) in which he reported his observations supporting the heliocentric model.



SIDEREVS
NVNCIVS
MAGNA, LONGEQVE ADMIRABILIA
Spectacula pandens, suspiciendaque proponens
vnicuique, praesertim verò
PHILOSOPHIS, atq; ASTRONOMIS, quae à
GALILEO GALILEO
PATRITIO FLORENTINO
Patauini Gymnasij Publico Mathematico
PERSPICILLI
Nuper à se reperti beneficio sunt obseruata in LVNAE FACIE, FIXIS INNVMERIS, LACTEO CIRCVLO, STELLIS NEBVLOSIS,
Apprime verò in
QVATVOR PLANETIS
Circa IOVIS Stellam disparibus interuallis, atque periodis, celeritate mirabili circumuolutis; quos, nemini in hanc vsque diem cognitos, nouissimè Author depraehendit primus; atque
MEDICEA SIDERA
NVNCVPANDOS DECREVIT.

VENETIIS, Apud Thomam Baglionum. M DC X.
Superiorum Permissu, & Priuilegio.

Heliocentrism was convicted in 1616 by the Catholic Church as *'foolish and absurd in philosophy, and formally heretical.'*

Models of the universe: geocentrism and heliocentrism

<u>Galileo Galilei</u>

In 1632 Galileo published ***Dialogo sopra i due massimi sistemi del mondo*** (*Dialogue Concerning the Two Chief World Systems*) in which he again supported the heliocentric model.

In 1633 Galileo was tried and convicted by the Inquisition, and forced to renounce his ideas.

Eppur si muove

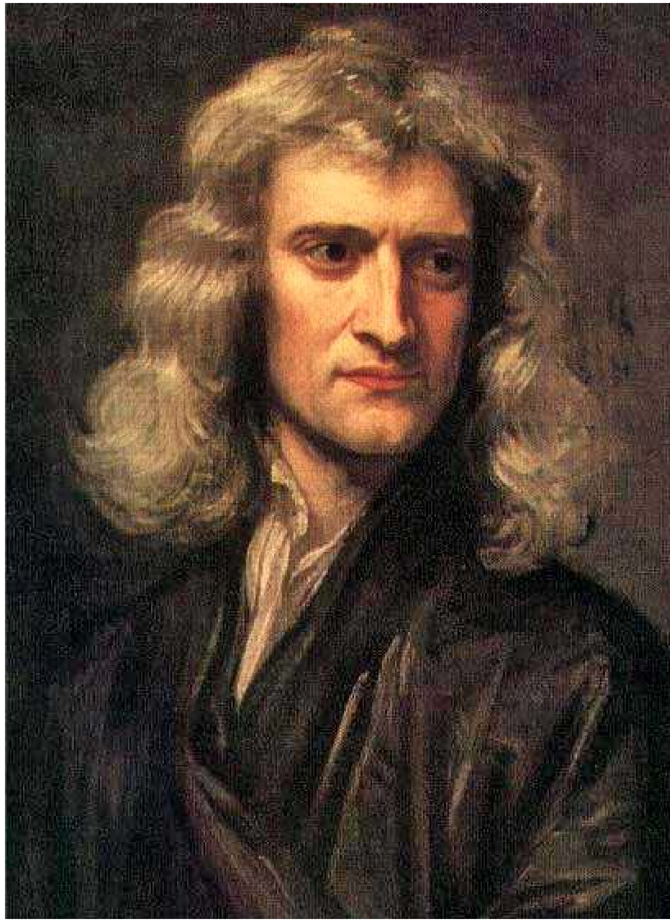
And yet it moves

Universal gravitation

Isaac Newton (1643-1727) formulated the basic laws that describe the **motion of objects**.

Newton's work demonstrated for the first time that ***the motion of objects on Earth and the motion of celestial objects are described by the same physical laws***.

Newton also made important contributions to the **theory of colour**, **optics,** and the development of **calculus**.



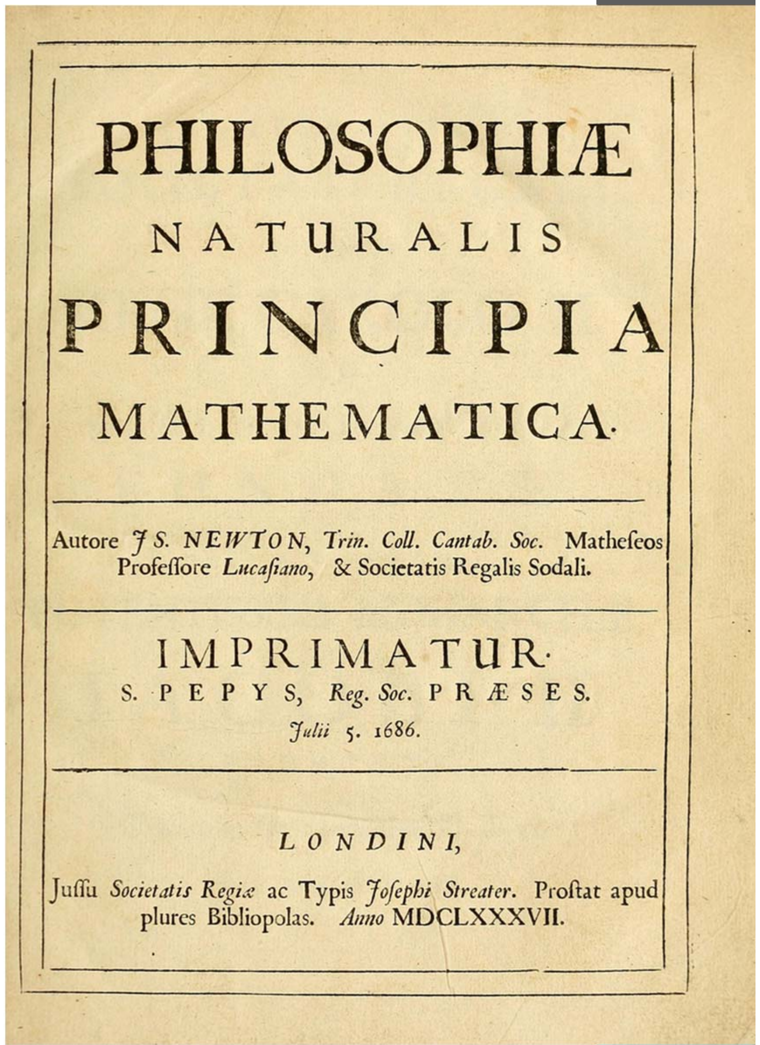
Universal gravitation

<u>Newton's laws of motion</u>

1. Every object remains at rest, or moves in a straight line at a constant velocity, unless acted upon by an outside force.

2. The acceleration of an object is directly proportional to the force acting upon it and is inversely proportional to its mass.

3. Whenever one body exerts a force upon a second body, the second body simultaneously exerts an equal and opposite force upon the first body.


PHILOSOPHIÆ
NATURALIS
PRINCIPIA
MATHEMATICA.

Autore *J S. NEWTON*, *Trin. Coll. Cantab. Soc.* Matheseos Professore *Lucasiano*, & Societatis Regalis Sodali.

IMPRIMATUR.
S. PEPYS, *Reg. Soc.* PRÆSES.
Julii 5. 1686.

LONDINI,

Jussu *Societatis Regiæ* ac Typis *Josephi Streater*. Prostat apud plures Bibliopolas. *Anno* MDCLXXXVII.

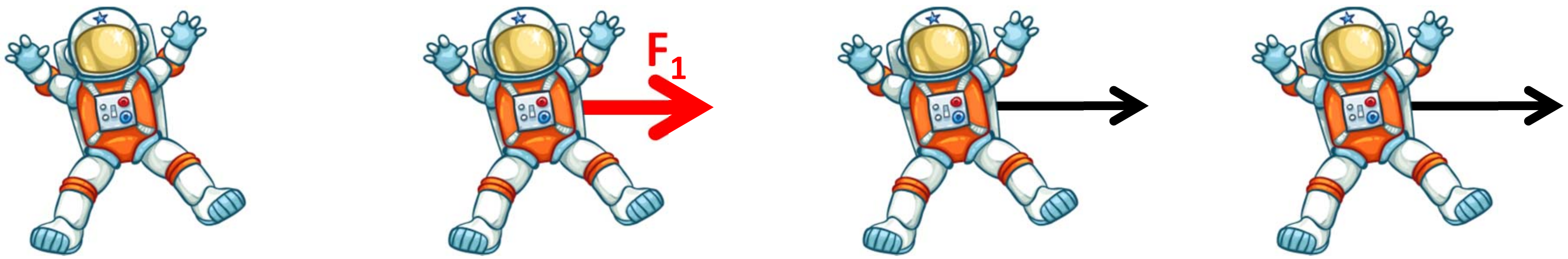
Philosophiæ naturalis principia mathematica
Isaac Newton. 1687

Universal gravitation

<u>Newton's first law</u>

Every object remains at rest, or moves in a straight line at a constant velocity, unless acted upon by an outside force.

Example:



$v_0 = 0$
$a_0 = 0$
$F_0 = 0$

$v_1 \neq 0$
$a_1 \neq 0$
$F_1 \neq 0$

$v_2 = v_3 \neq 0$
$a_2 = a_3 = 0$
$F_2 = F_3 = 0$

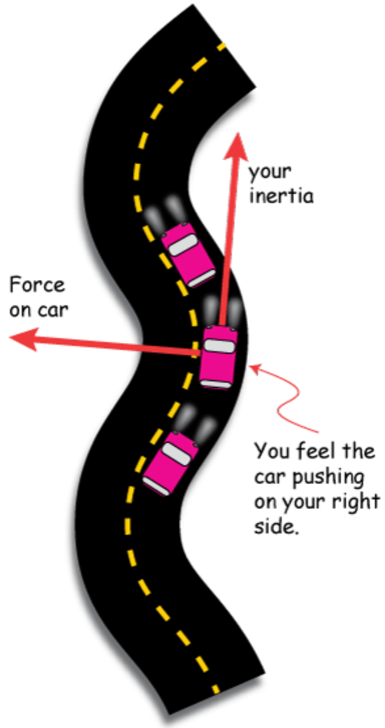
Universal gravitation

<u>Newton's first law</u>

Every object remains at rest, or moves in a straight line at a constant velocity, unless acted upon by an outside force.

It is the natural tendency of objects to resist changes in their state of motion. This is called **inertia**.

Example:



Universal gravitation

<u>Newton's first law</u>

Every object remains at rest, or moves in a straight line at a constant velocity, unless acted upon by an outside force.

Thus, a **force** is needed to **change the motion** of an object, but a force is NOT needed to keep an object in motion.

What does 'change the motion' mean?

- Move faster
- Move slower
- Change direction

→ **A force is needed!**

Forces cause changes in velocity, i.e., accelerations.

<u>Newton's second law</u>

The acceleration of an object is directly proportional to the force acting upon it and is inversely proportional to its mass.

i.e.,

acceleration (a) ↑ when force (F) ↑

acceleration (a) ↓ when mass (m) ↑

Therefore,

$$\boxed{F = m \cdot a}$$

Universal gravitation

<u>Newton's second law</u>

The acceleration of an object is directly proportional to the force acting upon it and is inversely proportional to its mass.

The forces acting upon an object can be of two types:

- **contact forces**: **tension force**, **normal force**, **frictional force,** and **spring force**.

- **action-at-a-distance forces**: **gravitational force**, **electromagnetic force**, **strong nuclear force,** and **weak nuclear force**.

<u>Newton's second law</u>

The acceleration of an object is directly proportional to the force acting upon it and is inversely proportional to its mass.

Example:

If we have two identical shopping carts, and we want one of them to reach a certain speed before the other cart, should we apply a force that is greater, lesser, or equal to the other shopping cart?

$F_1 > F_2$ **if** $a_1 > a_2$

Universal gravitation

Newton's second law

The acceleration of an object is directly proportional to the force acting upon it and is inversely proportional to its mass.

Example:

If we have two shopping carts with different masses, and we want both to reach a certain speed at the same time, should we apply an identical force to both shopping carts?

$F_1 > F_2$ if $m_1 > m_2$

Newton's second law

The acceleration of an object is directly proportional to the force acting upon it and is inversely proportional to its mass.

Mass is measured in kilograms (kg) and acceleration in m/s^2.

What are the units of force?

$$F = m \cdot a$$

$$[F] = kg \cdot m/s^2 = N$$

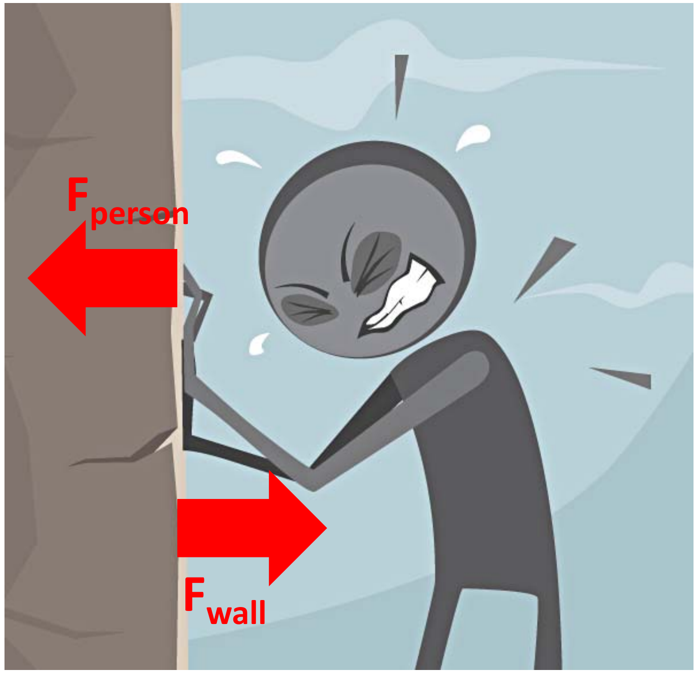
The unit of force in the International System of Units is the **newton**, which is the force required to accelerate a 1 kg mass at a rate of 1 m/s^2.

Newton's third law

Whenever one body exerts a force upon a second body, the second body simultaneously exerts an equal and opposite force upon the first body.

Thus, **for every action there is an equal and opposite reaction**.

Example:

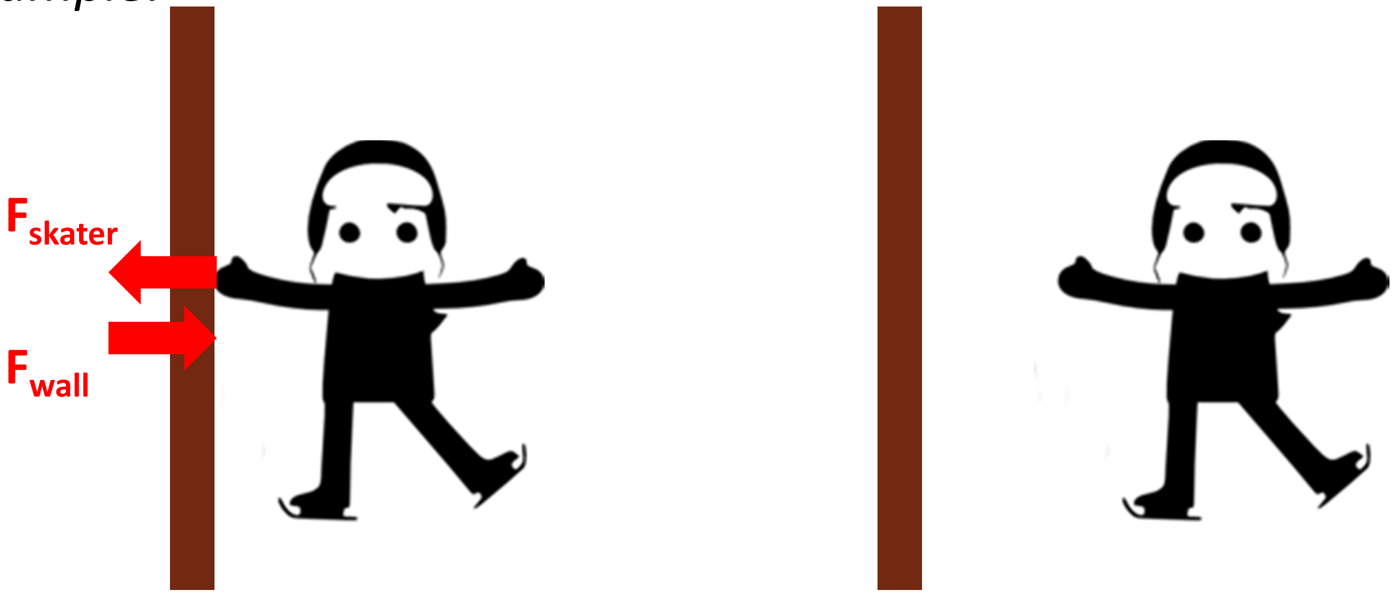


Universal gravitation

<u>Newton's third law</u>

Whenever one body exerts a force upon a second body, the second body simultaneously exerts an equal and opposite force upon the first body.

Example:



Universal gravitation

Newton’s third law

Whenever one body exerts a force upon a second body, the second body simultaneously exerts an equal and opposite force upon the first body.

Example:

Image: Joebrunton
CC BY-SA 3.0

Universal gravitation

<u>Newton's third law</u>

Whenever one body exerts a force upon a second body, the second body simultaneously exerts an equal and opposite force upon the first body.

Example:

Image: NASA

Universal gravitation

"That planets may be retained in certain orbits, we may easily understand, if we consider the motions of projectiles; for a stone projected is by the pressure of its own weight forced out of the rectilinear path, which by the projection alone it should have pursued, and made to describe a curved line in the air; and through that crooked way is at last brought down to the ground; and the greater the velocity is with which it is projected, the farther it goes before it falls to the Earth. We may therefore suppose the velocity to be so increased, that it would describe an arc of many miles before it arrived at the Earth, till at last, exceeding the limits of the Earth, it should pass quite by without touching it."

Isaac Newton

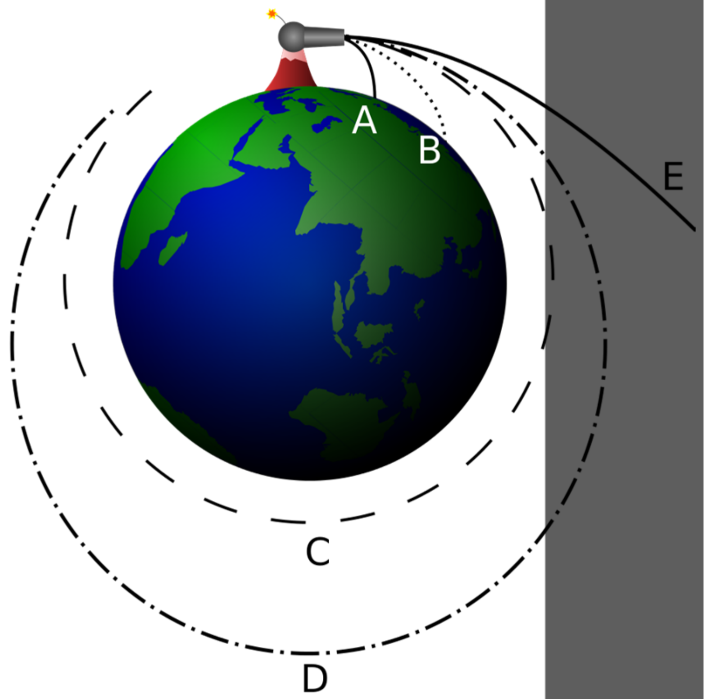


Image: Brian Brondel
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Universal gravitation

Universal law of gravitation

Newton analysed the work of several previous scientists (Galileo, Copernicus, Kepler) before formulating the universal law of gravitation.

Image: Frits Ahlefeldt
CC BY-NC-ND 2.0

Every object, simply because it has mass, exerts a force of attraction on other distant objects which also have mass.

This force of attraction is called **gravitational force**.

Universal gravitation

Universal law of gravitation

Every object attracts every single other object by a force which is proportional to the product of the two masses and inversely proportional to the square of the distance between them.

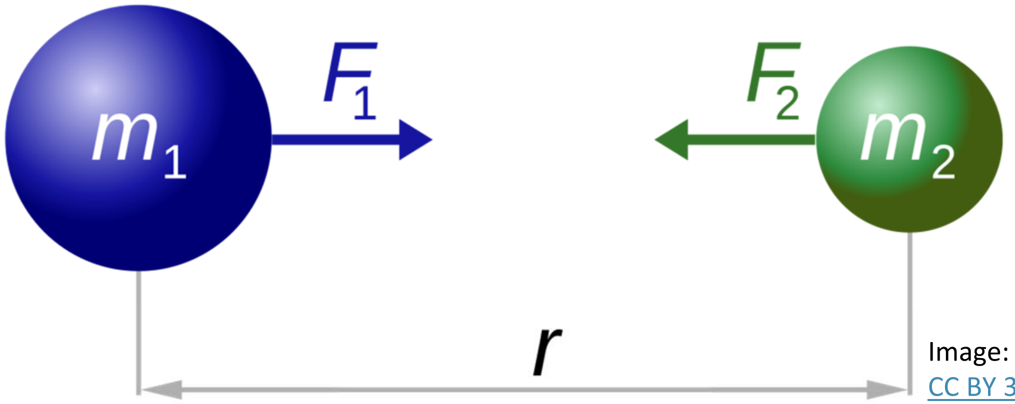


Image: Dennis Nilsson
CC BY 3.0

$$F_1 = F_2 = G\frac{m_1 \times m_2}{r^2}$$

G is the ***gravitational constant***: $G = 6.67 \times 10^{-11}\ Nm^2/kg^2$

Universal gravitation

Universal law of gravitation: consequences

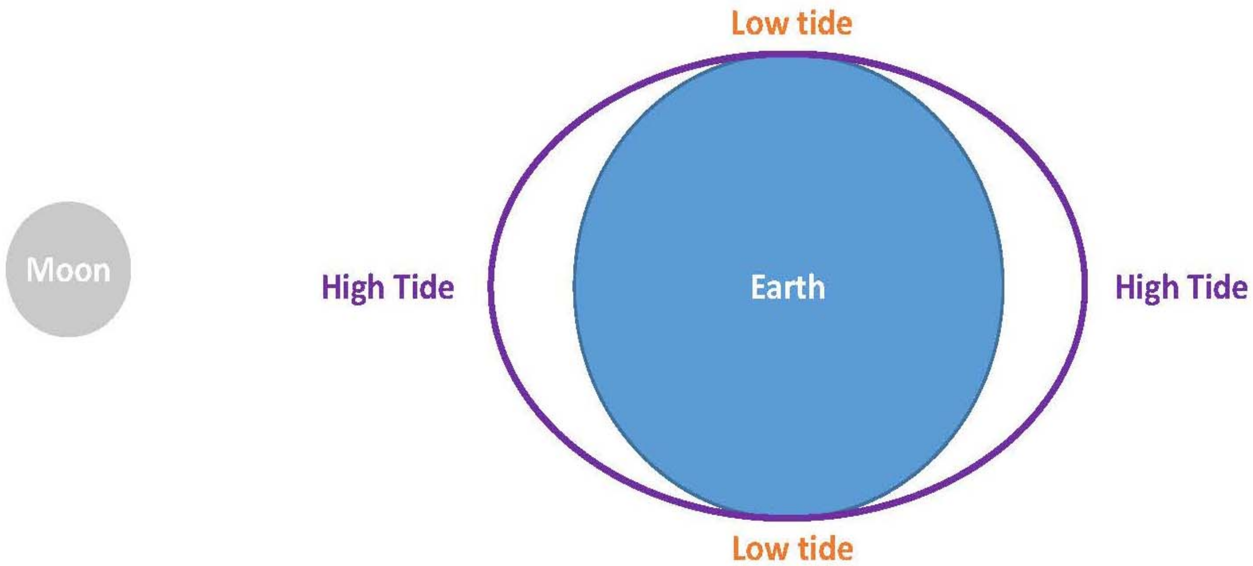
Tides are caused by the Moon (and to a lesser extent by the Sun) which pulls the ocean towards it provoking the rise of sea levels.

Image: Samuel Wantman
CC BY-SA 3.0

Universal gravitation

Universal law of gravitation: consequences

The Earth's oceans on the side closest to the Moon are pulled towards it by its gravitational force of attraction (**high tide**). In turn, the Moon's gravitational pull over the oceans on the side farthest from it is weaker than over the whole of Earth, and thus that mass of water 'lags behind' the Earth's surface (**high tide**). Since the Earth's mass of water is 'stretched' in two extremes, **low tides** originate in the other extremes.

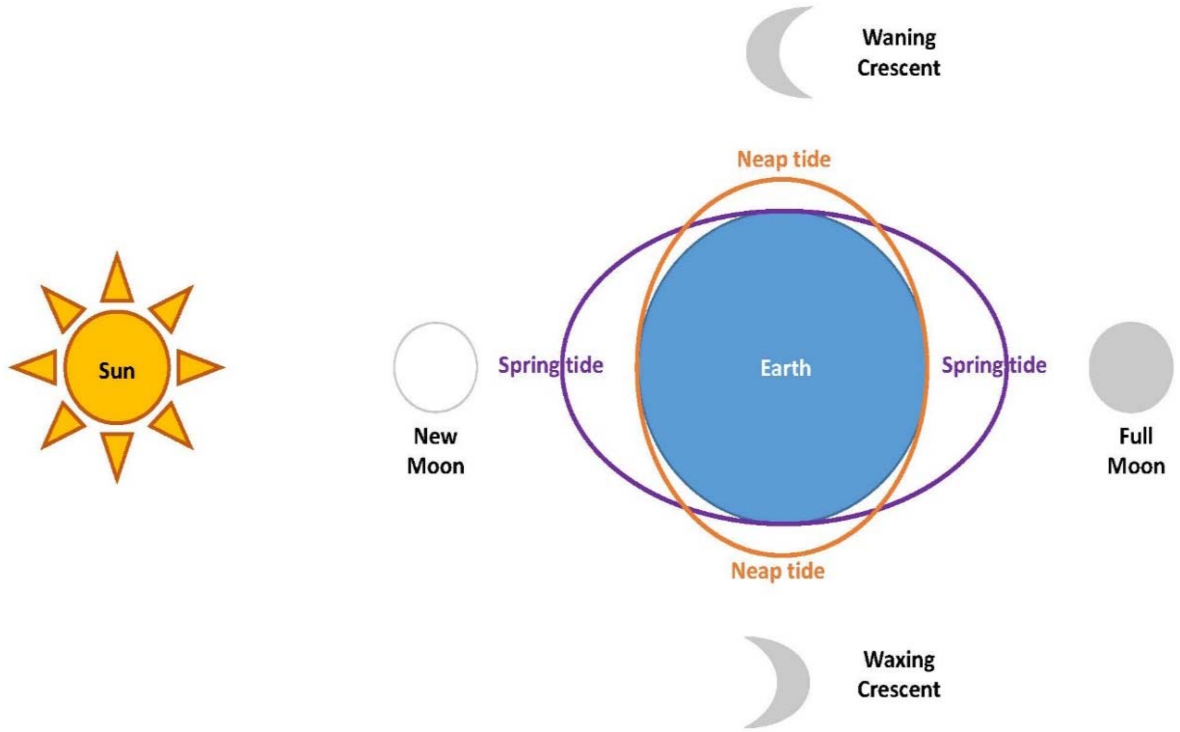


Universal gravitation

Universal law of gravitation: consequences

When the Sun is aligned with the Moon, the amplitude of the tides is maximal (**spring tides** during new and full moons).

When the Sun is at an angle of 90° with the Moon, the amplitude of the tides is minimal (**neap tides** during waxing and waning crescents).



Universal law of gravitation: consequences

The periodic behavior of **comets** is due to the fact that they describe highly eccentric elliptical orbits around the Sun.

Image: NASA/W. Liller

Halley's Comet orbits the Sun with a period of about 75 years. It was observed near the Earth in 1986, and its next appearance will occur in 2061.

Universal law of gravitation: consequences

Artificial satellites remain in a stable orbit around Earth as a result of the balance between:

- the satellite's **inertia**, which keeps it moving in a straight line.
- Earth's **gravitational force**, which constantly pulls the satellite towards Earth.

If v>> (inertia > gravity), the satellite will get lost in space.

If v<< (inertia < gravity), the satellite will fall on Earth.

The ***International Space Station*** orbits Earth at an altitude of 400 km with a speed of 7 706.7 m/s.

Image: NASA

Universal law of gravitation: consequences

The **oblate spheroid shape of the planets** is the result of the combined effect of **gravitation** (which forms spheres with the initially scattered matter) and **rotation** around its axis (which forms a sphere flattened in the poles and with a bulge around the equator).

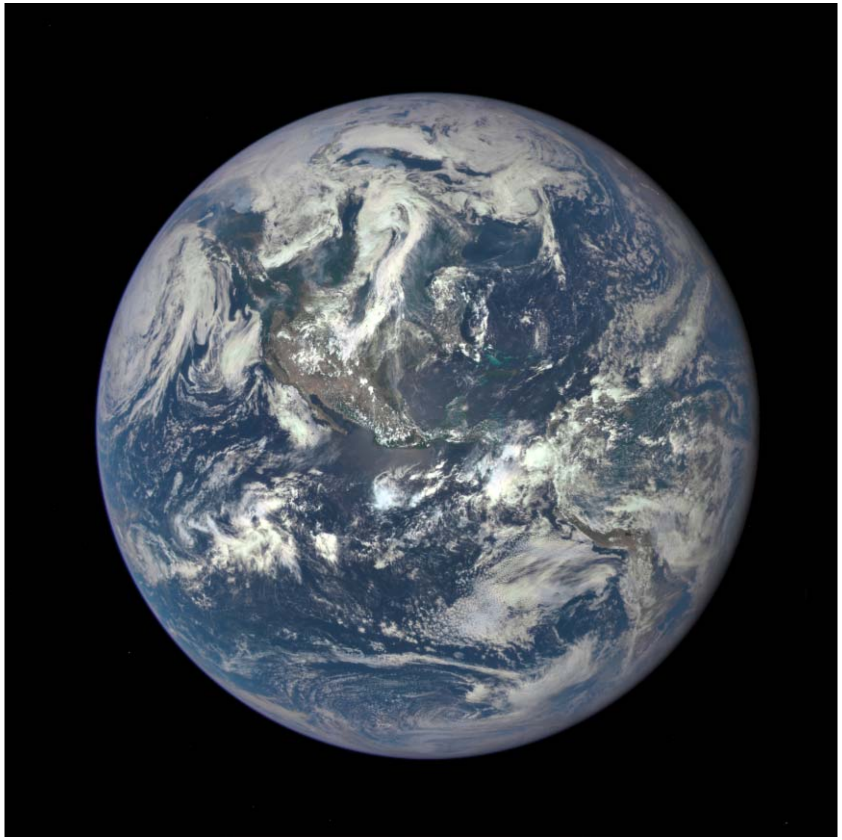


Image: Deep Space Climate Observatory. NASA. 2015.

Universal gravitation

Universal law of gravitation: consequences

The **discovery of new planets** is possible from the gravitational perturbations caused to the orbits of already known planets.

For example, ***irregularities in Uranus' orbit*** (W. Herschel, 1781) led to the ***discovery of Neptune*** (U. Le Verrier and J.C. Adams, 1846).

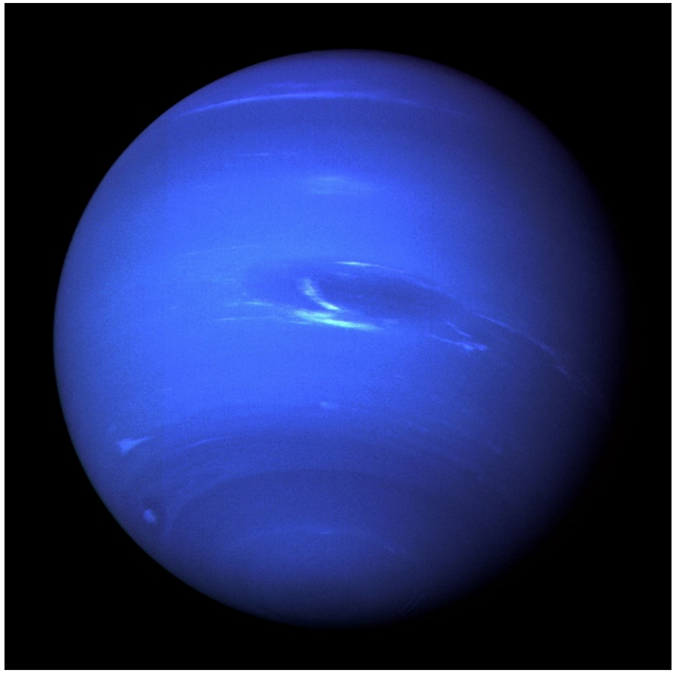


Image: NASA

Universal gravitation

Gravity

Gravity is the gravitational force of attraction between two astronomical objects that draws them towards one another.

This force is also called **weight** (W).

According to Newton's **universal law of gravitation**:

$$F = G\frac{M\,m}{d^2}$$

g

According to Newton's **second law of motion**:

$$F = m \cdot a \rightarrow W = m \cdot g$$

Universal gravitation

Gravity

The gravitational constant, G, is:

$G = 6.67\times10^{-11}\ Nm^2/kg^2$

In the case of Earth,

$M = 5.97\times10^{24}\ kg$

$d = 6\ 371\ km$

Thus,

$$g = G\frac{M}{d^2} = (6.67 \times 10^{-11}\ Nm^2/kg^2) \times \frac{(5.97 \times 10^{24}\ kg)}{(6\ 371\ 000\ m)^2} = 9.8\ m/s^2$$

Objects in free fall near the Earth's surface accelerate down at 9.8 m/s^2!

Current knowledge of the universe

The solar system

The solar system consists of the **Sun** and all other astronomical objects that move around it.

Eight planets revolve around the Sun: Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus and Neptune.

Other astronomical objects also in the solar system are:

- **satellites** (Earth’s *Moon* or Saturn's *Titan*)
- **asteroids** (the *asteroid belt* between Mars and Jupiter)
- **comets**
- ...

Current knowledge of the universe

The solar system

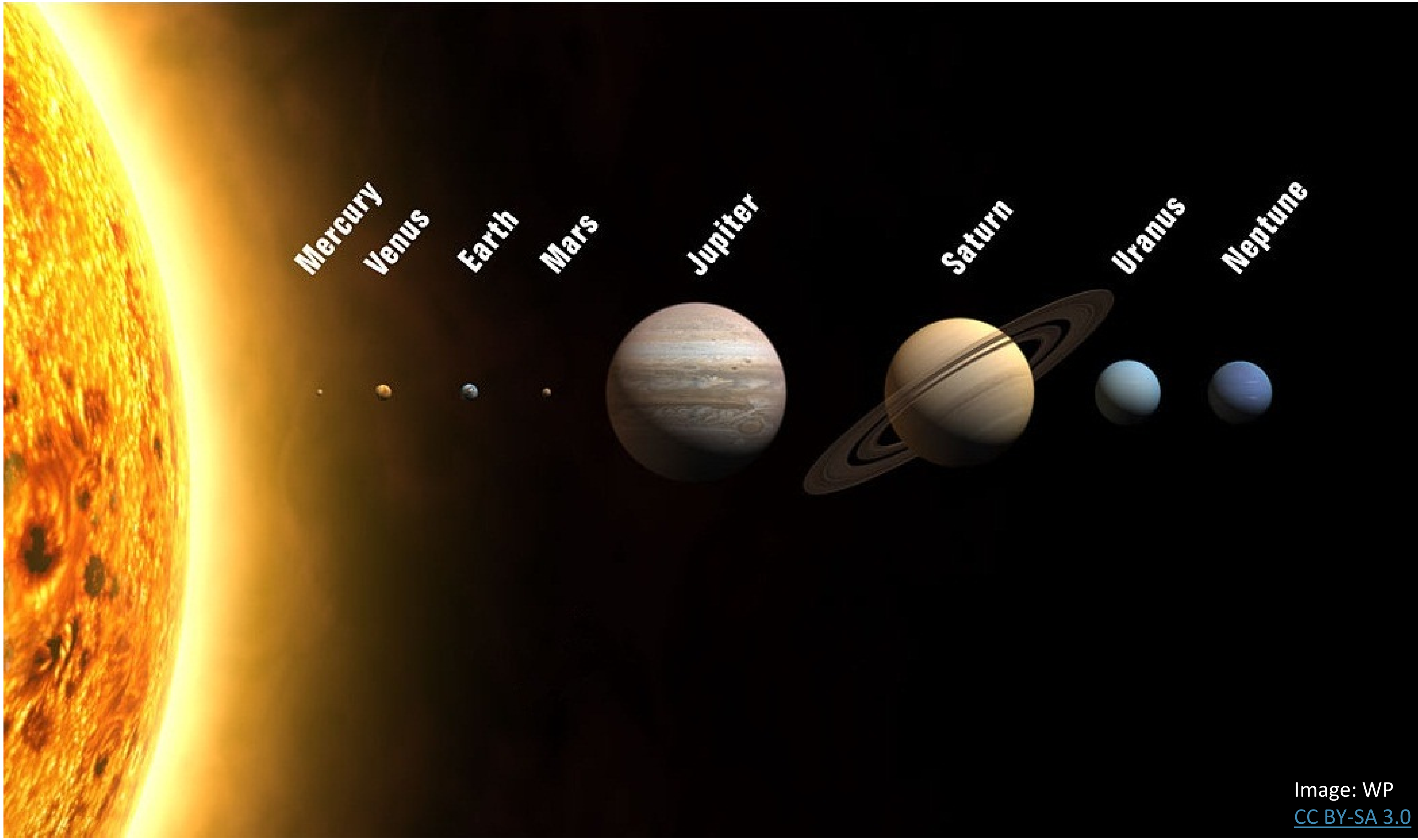


Image: WP
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Current knowledge of the universe

The solar system

What about Pluto ... is it a planet or not?

When Pluto was discovered in 1930, it was considered the ninth, smallest, and the most distant planet in the solar system.

There are also similar objects beyond Neptune's orbit which are not considered planets.

In **2006** Pluto was reclassified as a ***dwarf planet*** because it is very small and its orbit is highly eccentric and very different to those of other planets.

In **14 July 2015,** NASA's space probe ***New Horizons*** flew 12 500 km above Pluto's surface.

Image: NASA/Johns Hopkins University Applied Physics Laboratory/Southwest Research Institute

Current knowledge of the universe

The solar system: the Sun

The **Sun** is the **star** at the center of the **solar system** and it is its largest source of radiation.

It is a medium-sized star, mainly composed of **hydrogen** (75%), **helium** (20%) and other elements (5%).

It produces **energy** by **nuclear fusion** taking place deep inside.

It **rotates around its own axis**, with a period of **27 days**.

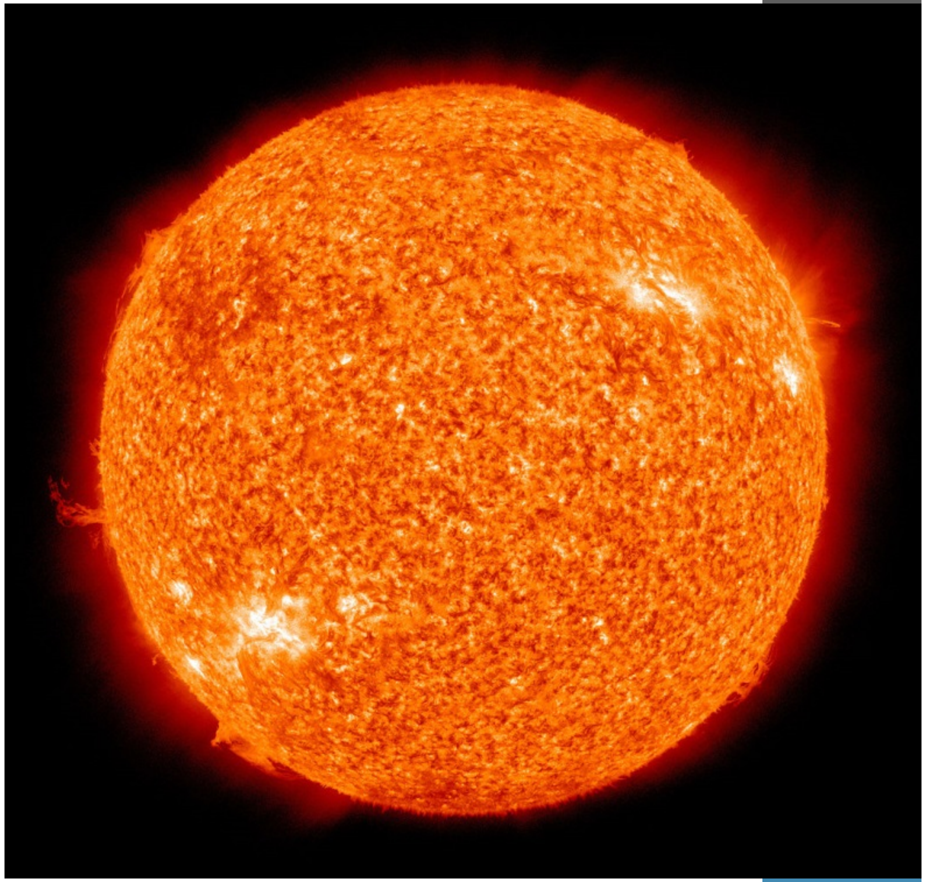


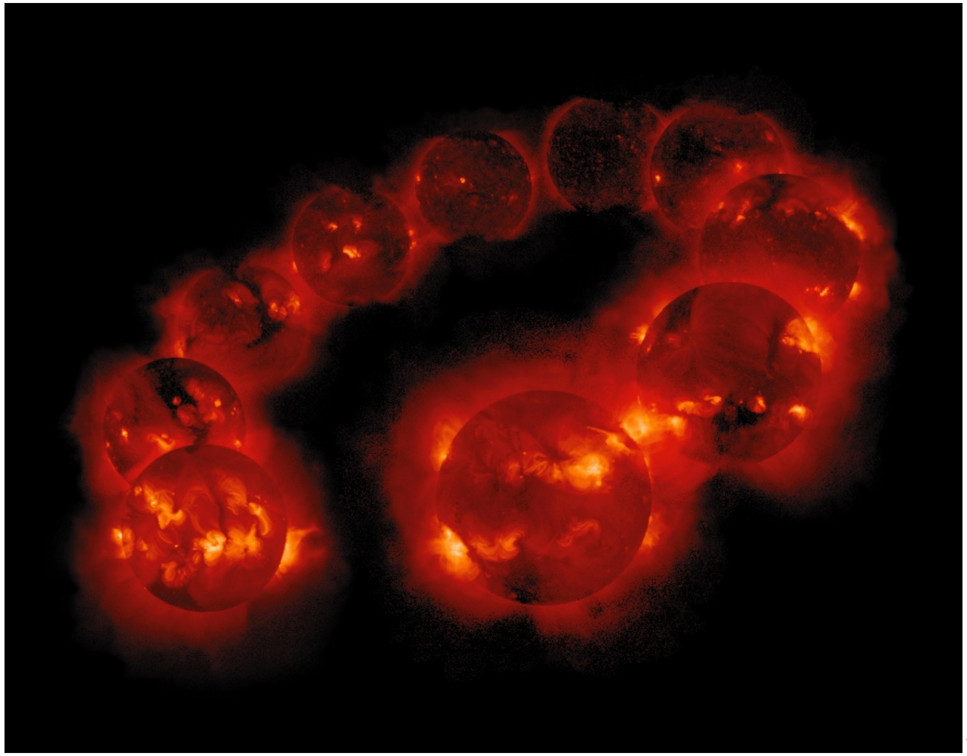
Image: NASA/SDO (AIA)

Current knowledge of the universe

The solar system: the Sun

The Sun's surface is not uniform, since darker regions (**sunspots**) where the temperature is lower (~2 000°C below the surrounding areas) can be observed.

The number and size of sunspots varies periodically every **11 years** (**solar cycle**).



Solar cycle 30/08/1991 - 06/09/2001.
Image: Yohkoh. ISAS & NASA.
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Current knowledge of the universe

The solar system: the Sun

Solar flares, which are very violent and energetic phenomena, can also be observed near the Sun's surface. They eject clouds of particles (electrons, ions, etc.) into space that provoke ***auroras*** when reaching Earth.

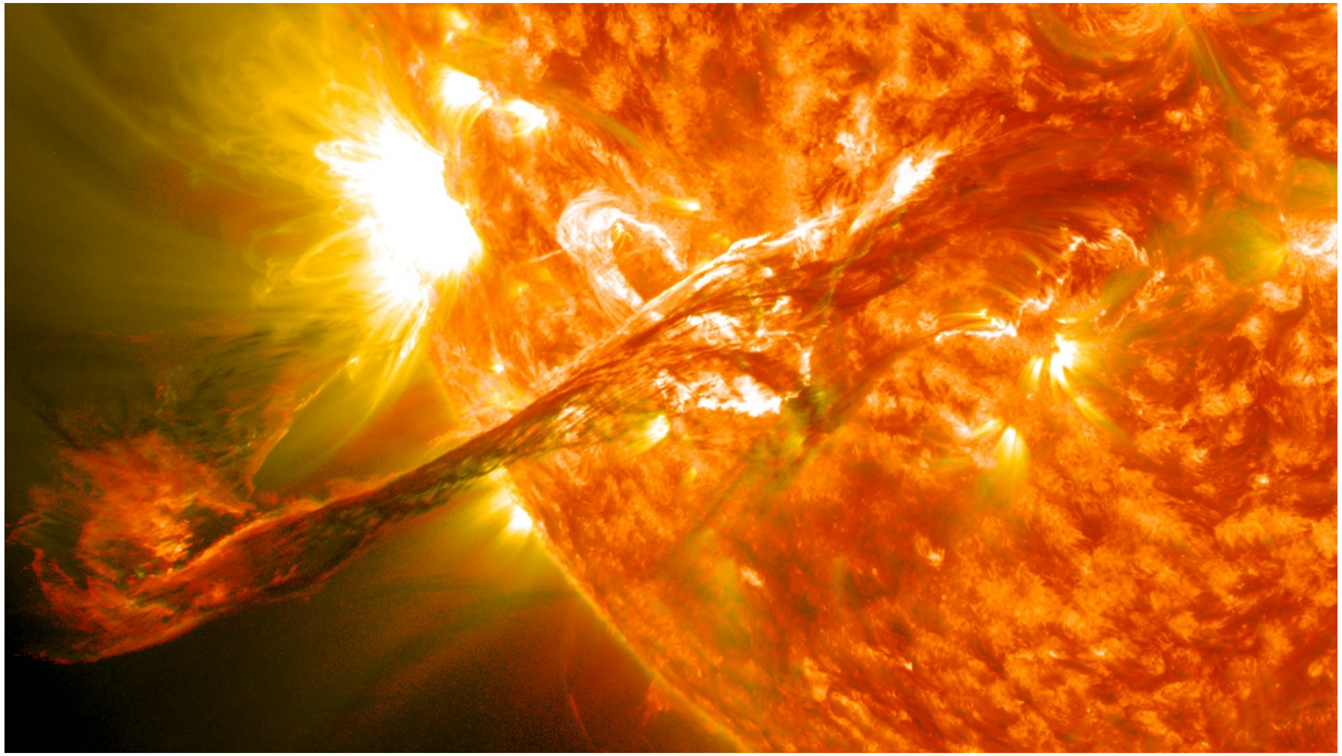

Image: NASA/GSFC/SDO
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Current knowledge of the universe

<u>The solar system: the Sun</u>

The Sun was formed about 4 567 million years ago.

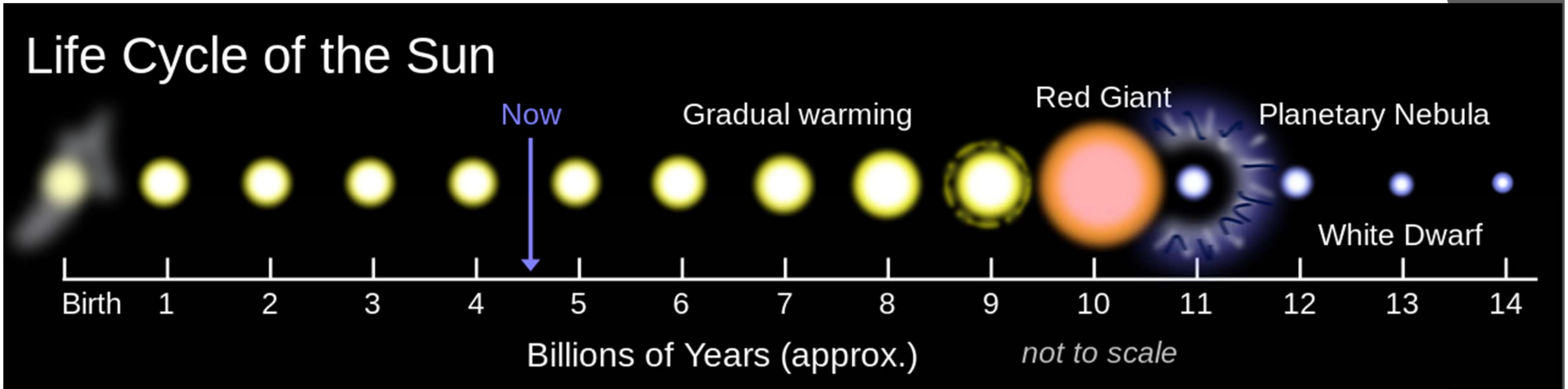


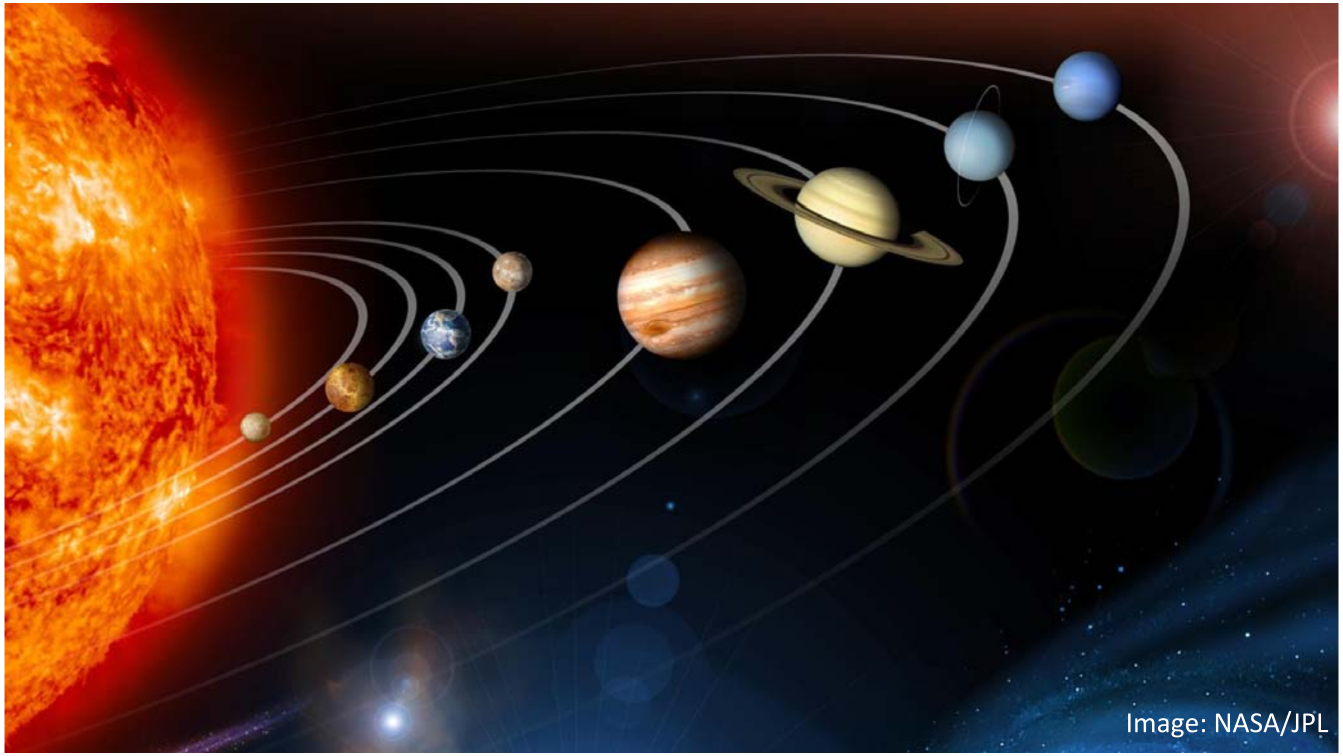
Image: Oliverbeatson

During 4 000 million years it has not changed much, and will remain fairly stable for 4 000 million more years.

However, after the hydrogen is exhausted, the Sun will undergo severe changes.

Current knowledge of the universe

The solar system: the planets



Revolving around the Sun there are eight planets. According to the radius of their orbits (i.e., their distance to the Sun), we can distinguish:

- **Inner planets:** Mercury, Venus, Earth and Mars.
- **Outer planets:** Jupiter, Saturn, Uranus and Neptune.

The solar system: the planets

The **inner planets** are the four planets closest to the Sun: **Mercury**, **Venus**, **Earth** and **Mars**.

They are small and dense (3 - 5 g/cm^3), and composed primarily of silicate rocks and metals.

Mercury, Venus, Earth and Mars have solid surfaces.

Venus, Earth, and Mars also have an atmosphere.

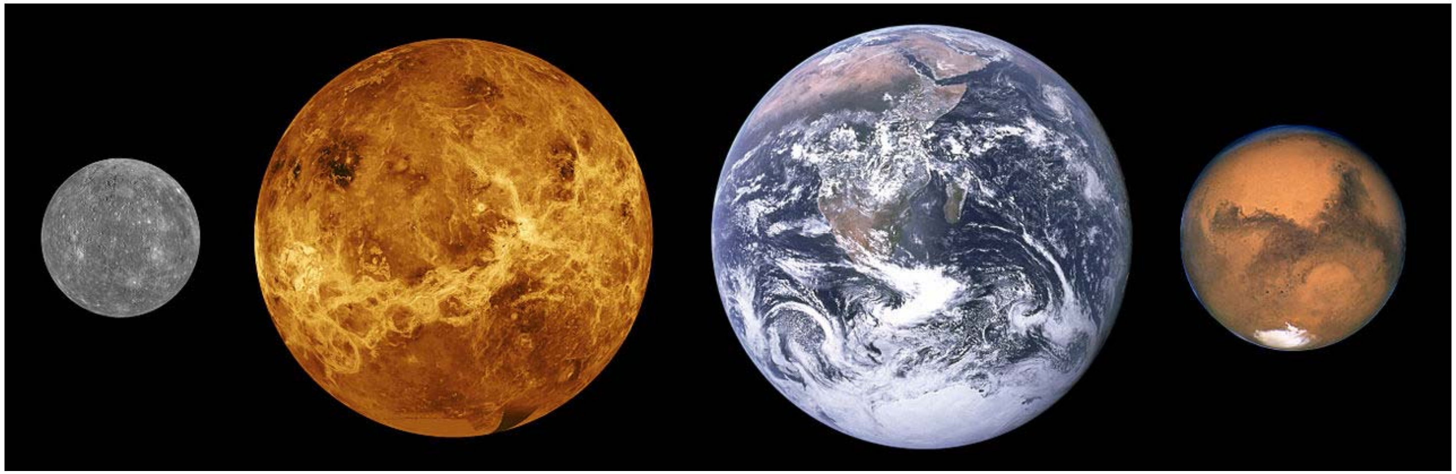


Image: NASA/JHUAPL/JPL/HST

Current knowledge of the universe

The solar system: the planets

The **outer planets** are the four planets farthest from the Sun: **Jupiter**, **Saturn**, **Uranus** and **Neptune**.

They are very large and light (0.7 – 1.6 g/cm^3), and are mainly composed of gases.

Jupiter and **Saturn** are called ***gas giants*** because they are mainly composed of hydrogen and helium, while **Uranus** and **Neptune** are called ***ice giants*** because they have icy cores mainly composed of heavier elements (oxygen, carbon, nitrogen, etc.).

They all have many **natural satellites**.

They all have **ring systems**.

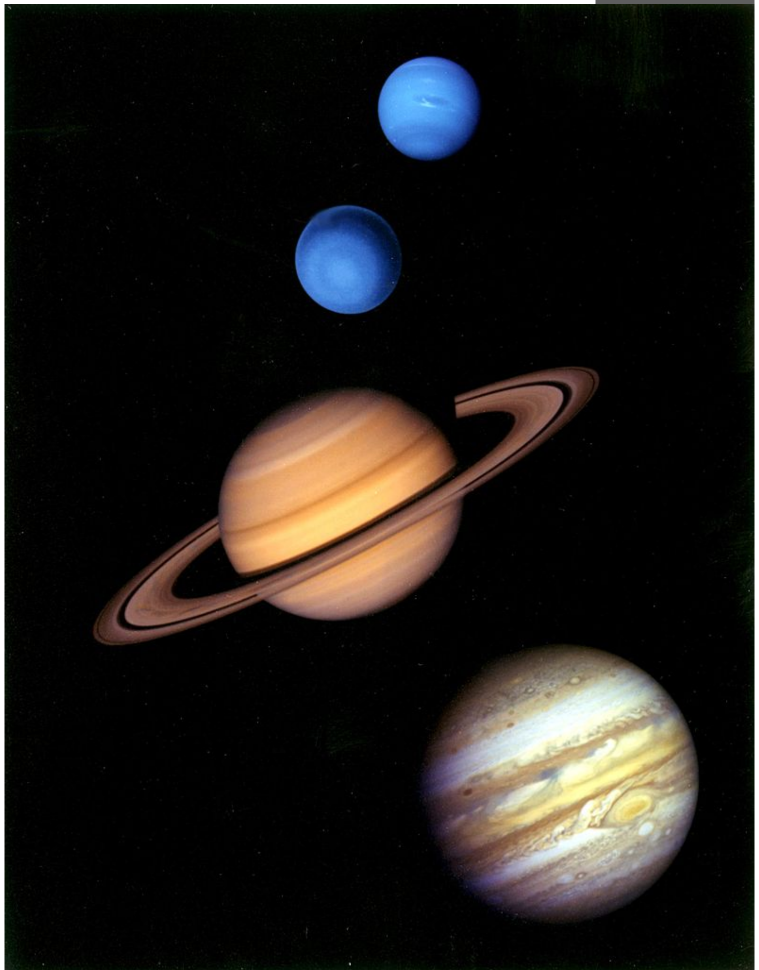


Image: NASA

Current knowledge of the universe

The solar system: the planets

Planet	Radius (km)	Mass (kg)	Distance to the Sun (UA)	Orbital period (years)	Satellites
Mercury	4 870	3.20×10^{23}	0.39	0.24	--
Venus	12 103	4.87×10^{24}	0.72	0.62	--
Earth	12 756	5.9×10^{24}	1.00	1.00	Moon
Mars	6 786	6.42×10^{23}	1.52	1.88	Phobos and Deimos
Jupiter	142 984	1.90×10^{27}	5.20	11.8	Io, Europa, Ganymede, Callisto *…(67)*
Saturn	120 536	5.68×10^{26}	9.54	29.5	Titan, Hyperion, Iapetus *…(62)*
Uranus	51 118	8.68×10^{25}	19.19	84	Miranda, Ariel, Umbriel, Titania, Oberon *…(27)*
Neptune	49 528	1.02×10^{26}	30.06	165	Triton, Nereid *…(14)*

The solar system: dwarf planets, asteroids and comets

Dwarf planets are objects that orbit the Sun, and are massive enough to be spherical, but have not cleared the neighborhood around its orbit. These are: **Ceres**, **Pluto**, **Eris**, **Makemake** and **Haumea**.

Between the orbits of Mars and Jupiter there is a region occupied by numerous asteroids (irregularly shaped rocky bodies that orbit the Sun). This is the **asteroid belt**.

Comets are objects composed of rocks and ice that orbit the Sun with highly eccentric orbits. When passing close to the Sun, they display a long tail of gas and dust often visible to the naked eye.

Current knowledge of the universe

Stars

Stars are large astronomical objects inside which **nuclear reactions** occur that cause the emission of large amounts of **energy** into space.

Image: NASA/ESA/AURA/Caltech /Palomar Observatory

Current knowledge of the universe

Stars

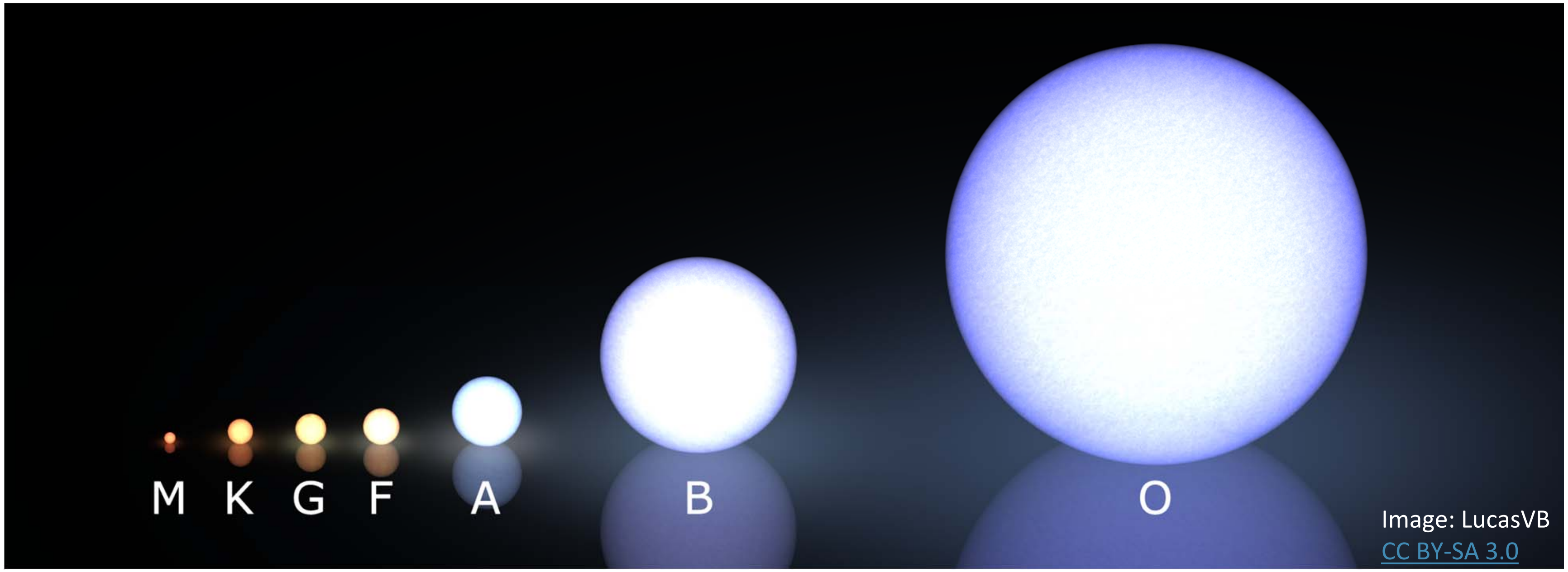
The nearest stars are far from the solar system.

Star	Distance (light-years)
Alpha Centauri	4.3
Sirius	8.6
Procyon	11.4
Tau Ceti	11.9
Vega	27
Arcturus	40
Capella	42
Aldebaran	55
Regulus	77
Antares	220

Current knowledge of the universe

Stars: classification

Stars can be classified by their **surface temperature** (i.e., colour).



Low temperature → **High temperature**

Stars: classification

Stars can be classified by their **surface temperature** (i.e., colour).

Star type	Colour	Surface Temperature (K)	Example
O	Blue	> 25 000	10 Lacertra
B	Blue	11 000 – 25 000	Rigel
A	Blue	7 500 – 11 000	Sirius
F	Blue – white	6 000 – 7 500	Procyon
G	White – yellow	5 000 – 6 000	Sun
K	Orange – red	3 500 – 5 000	Arcturus
M	Red	< 3 500	Betelgeuse

Current knowledge of the universe

Stars: classification

The **Hertzsprung–Russell diagram** shows the relationship between the star's brightness versus its temperature.

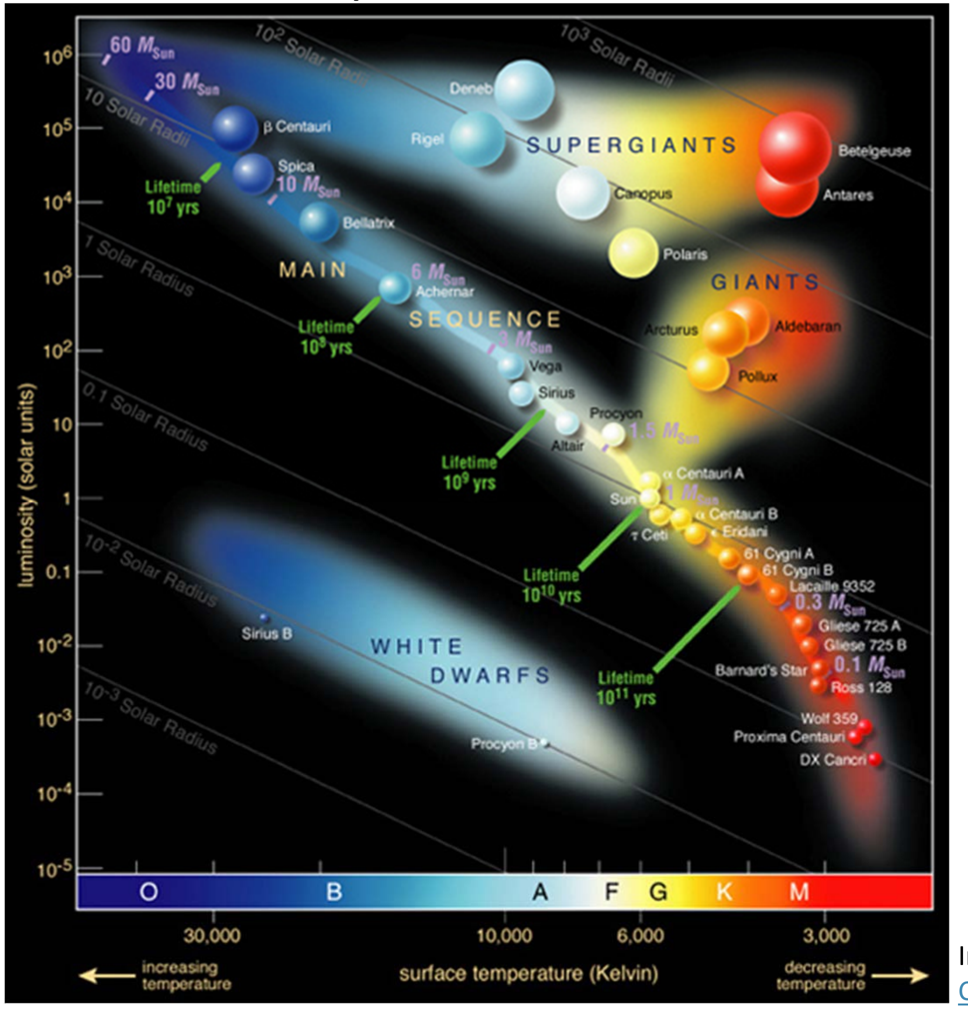


Image: ESO
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Stars: classification

The **Hertzsprung–Russell diagram** shows that there are three very different types of stars:

- Most stars are **'main sequence stars'**, fueled by nuclear fusion converting hydrogen into helium. For these stars, the hotter they are, the brighter. These stars are in the stablest part of their existence.
- As stars begin to die, they become **giants** and **supergiants** (above the main sequence). These stars have depleted their hydrogen supply and are very old. The core contracts as the outer layers expand.
- Smaller stars eventually become **white dwarfs** (below the main sequence), which are hot, shrinking stars that have depleted their nuclear fuels.

Current knowledge of the universe

Stars: classification

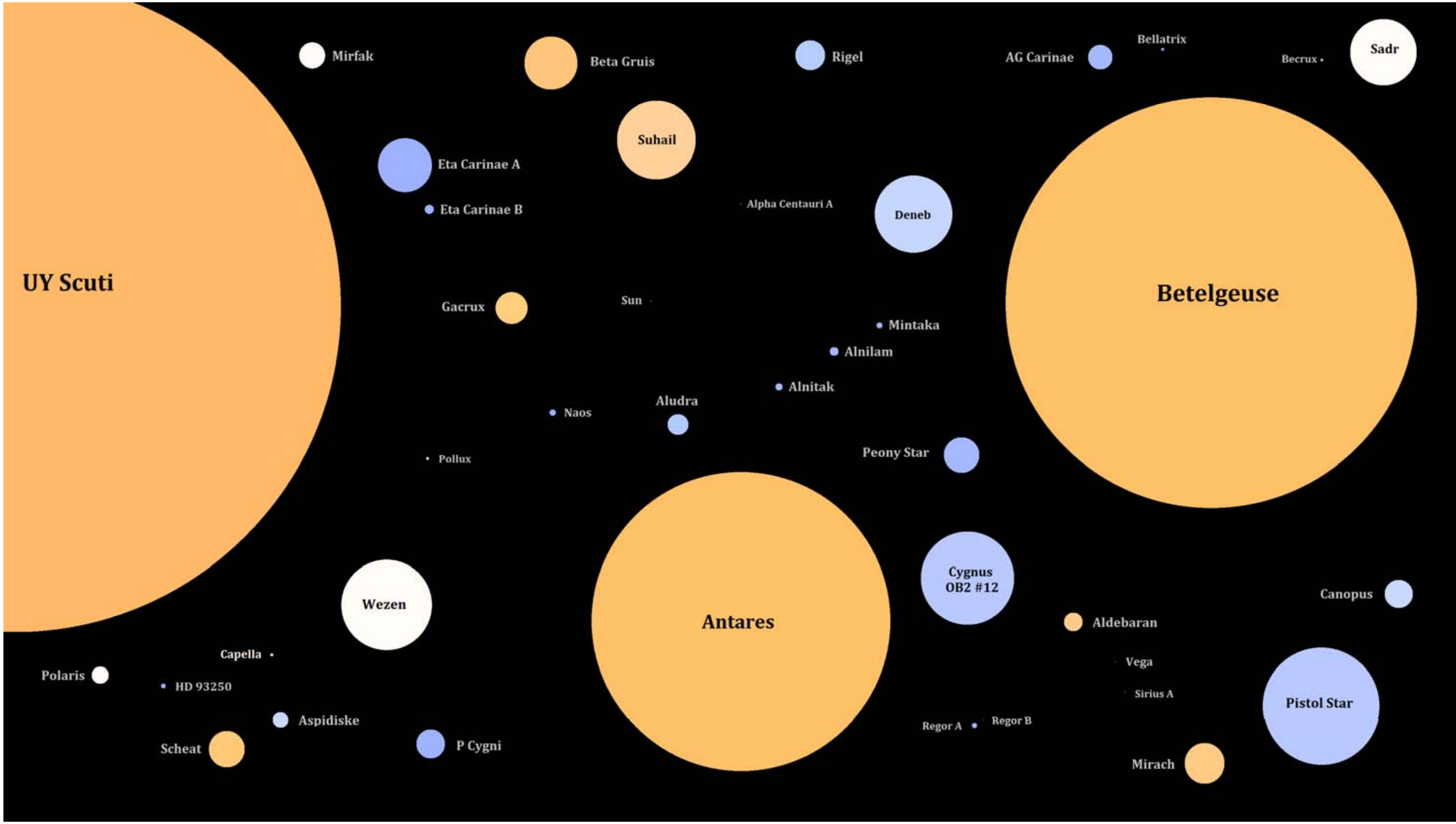

Image: GiovanniMartin16
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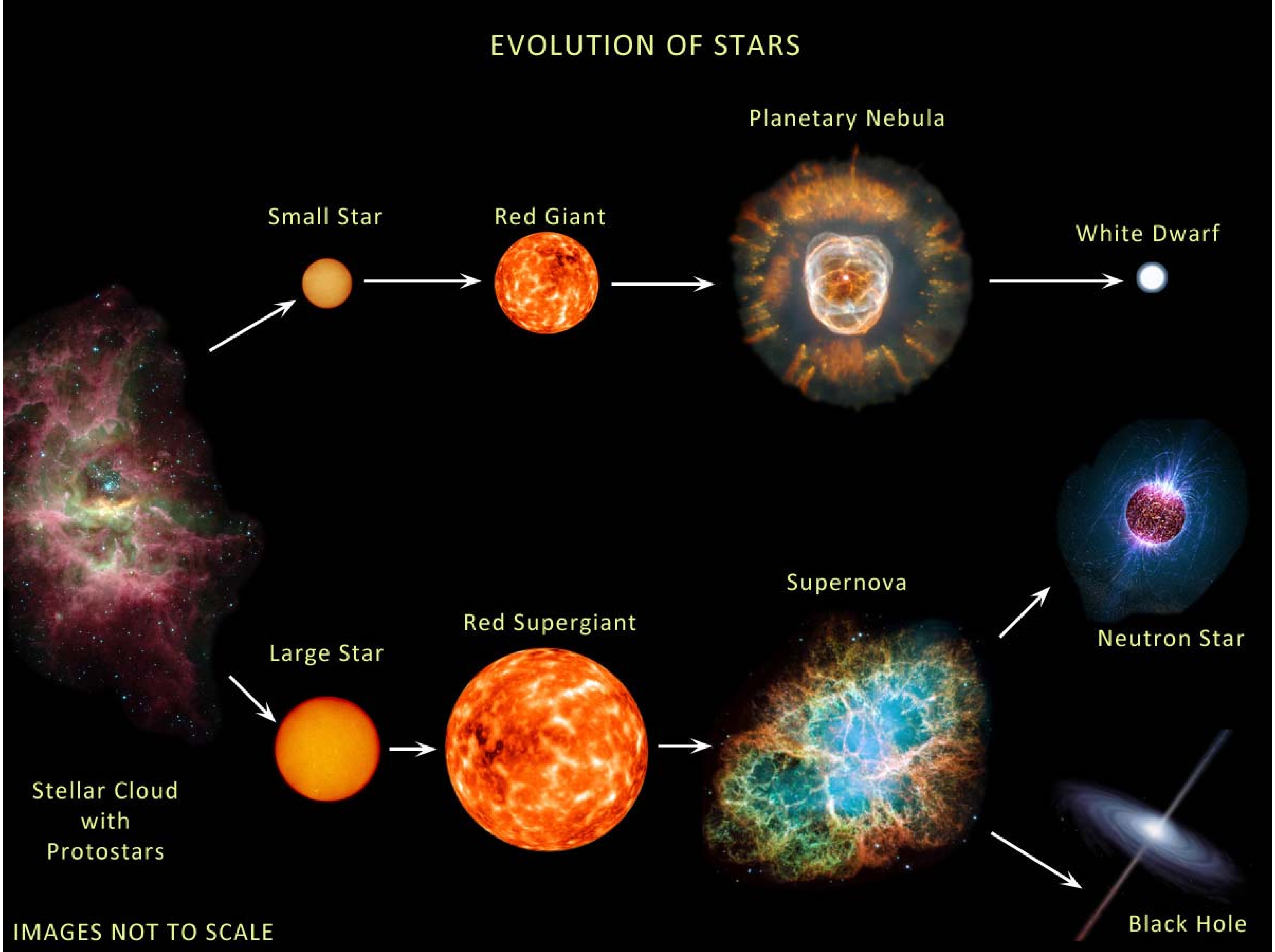

EVOLUTION OF STARS
Small Star
Red Giant
Planetary Nebula
White Dwarf
Stellar Cloud
with
Protostars
Large Star
Red Supergiant
Supernova
Neutron Star
Black Hole
IMAGES NOT TO SCALE

Stars: stellar evolution

Stars are born from large interstellar clouds of dust and gases called **nebulae**. Some regions within these clouds collapse due to gravity, starting to rotate faster and increasing in temperature to the point where nuclear reactions begin. At this point, hydrogen is converted into helium in the core of the star.

For millions of years, the star will burn hydrogen into helium.

What happens next depends on the mass of the star …

Stars: stellar evolution - low mass stars

Once the hydrogen in the core has all burned to helium, there is no longer any source of heat to support the core against gravity.

The core of the star collapses under gravity's pull until it reaches a high enough density to start converting helium to carbon. Meanwhile, the star's outer shell expands and the star evolves into a **red giant**.

The carbon core continues to contract as much as possible, forming a very dense star (~10^9 kg/m^3) called a **white dwarf**. Eventually, the outer layers of the star are ejected completely by the white dwarf to form a **planetary nebula**.

Stars: stellar evolution - massive stars

Once the hydrogen in the core has all been burnt to helium, the star's core collapses reaching high enough temperatures to continue the nuclear fusion cycle converting helium to carbon, oxygen, neon, silicon, sulphur, and finally to iron, which cannot be burned to heavier elements.

Without any source of heat to support the core against gravity, the iron core collapses under gravity's pull until it resists further collapse, producing a **supernova** explosion.

If the remaining core has a low mass, its collapse may be halted by nuclear forces, and it will cool to form a very small and highly dense (~10^{17} kg/m^3) **neutron star**.

If the remaining core is so heavy that not even nuclear forces can resist the pull of gravity, it will collapse further into a **black hole**, from which light radiation cannot escape.

Current knowledge of the universe

Galaxies

Galaxies are gravitationally bound systems, typically consisting of **stars**, **planets**, **gas** and **dust**.

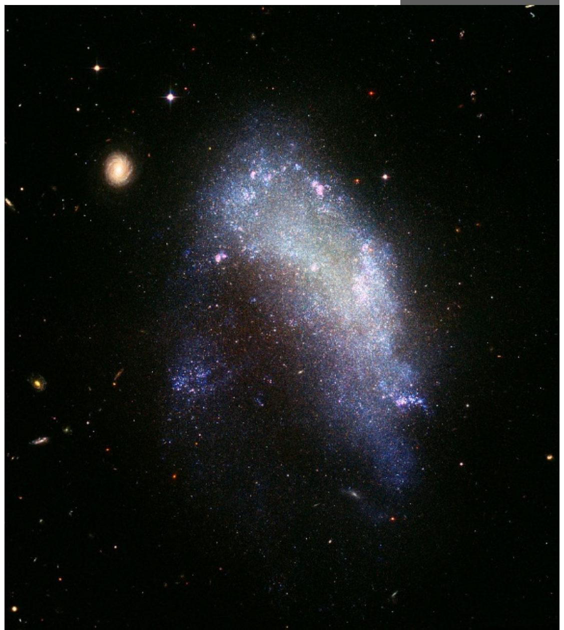
NGC 4414
Image: NASA/ESA

Current knowledge of the universe

Galaxies

Galaxies are classified according to their shape:

- **Elliptical:** no spiral arms and more or less regular shapes.
- **Spiral:** two or more spiral arms which radiate from a central bulge.
- **Irregular.**



Images: NASA, ESA and the Hubble Heritage Team (STScI/AURA)

Image: ESO/José Francisco Salgado
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Current knowledge of the universe

Galaxies

- A bright band of white light can be seen stretching across the night sky.
- This is the **Milky Way**, the galaxy which contains the Solar System.
- Until the early 20^{th} century, it was widely believed that the Milky Way contained all the stars in the **universe**.
- Observations made by **Edwin Hubble** in 1924 showed that the Milky Way is **just one of many galaxies** in the universe.

Image: Steve Jurvetson
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Current knowledge of the universe

Galaxies

The **Milky Way** …

- is a **spiral galaxy**.
- Its diameter is considered to be about 100 000 – 120 000 **light-years**.
- It is estimated to contain 200 000 – 400 000 million stars.
- The solar system is located about 27 000 light-years from the galactic center.

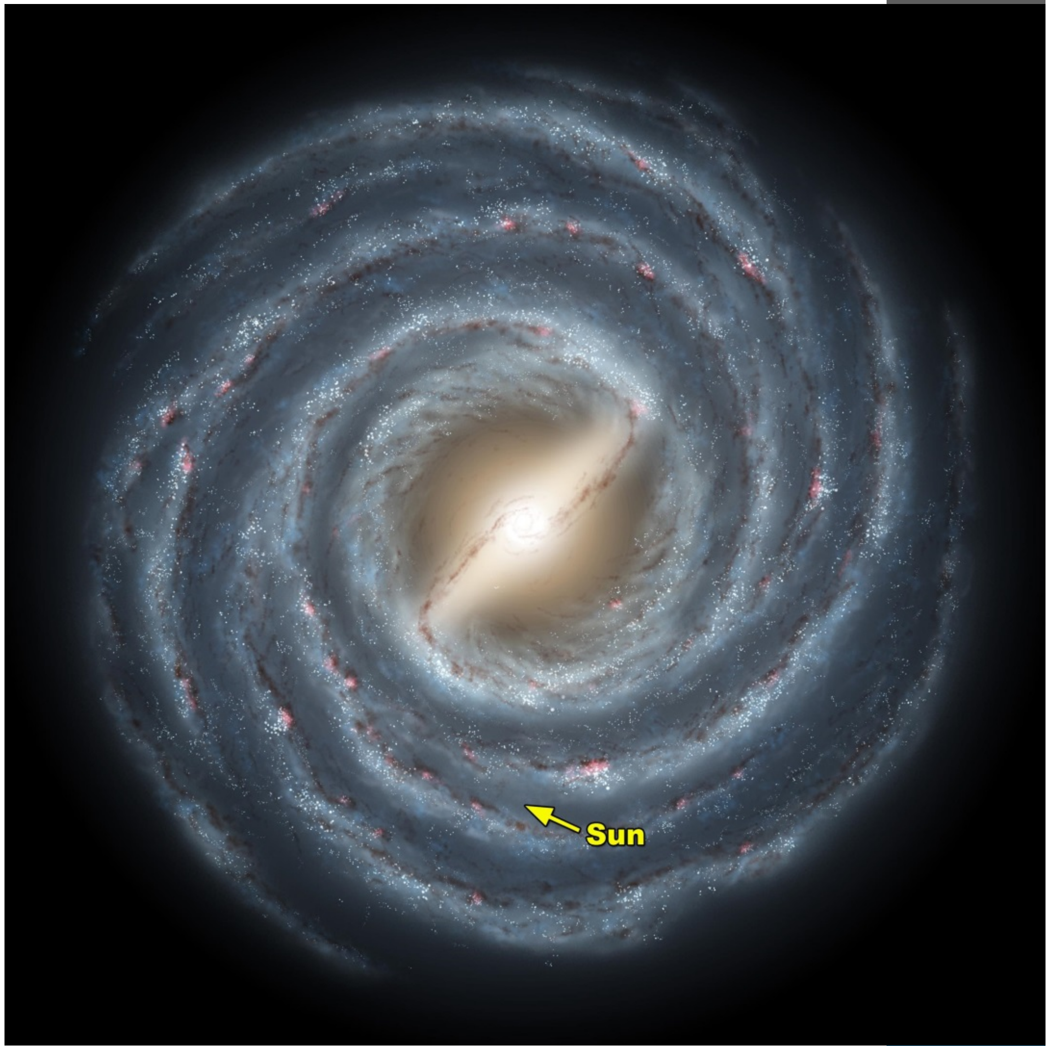

Image: R. Hurt/NASA/JPL

Current knowledge of the universe

Galaxies

The **Andromeda Galaxy** is the nearest major galaxy to the Milky Way (~2.5 million light-years from Earth). It is visible to the naked eye. It is estimated to contain 10^{12} stars.

Image: Boris Štromar
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Current knowledge of the universe

Galaxies

Galaxies are not generally found in isolation and most comprise part of larger, self-gravitating collections called **groups** and **clusters**.

The **Milky Way** and the **Andromeda Galaxy** are part of a gravitationally-bound group of around 40 galaxies known as the **Local Group**.

The Local Group is often considered to lie on the fringes of the **Virgo cluster**.

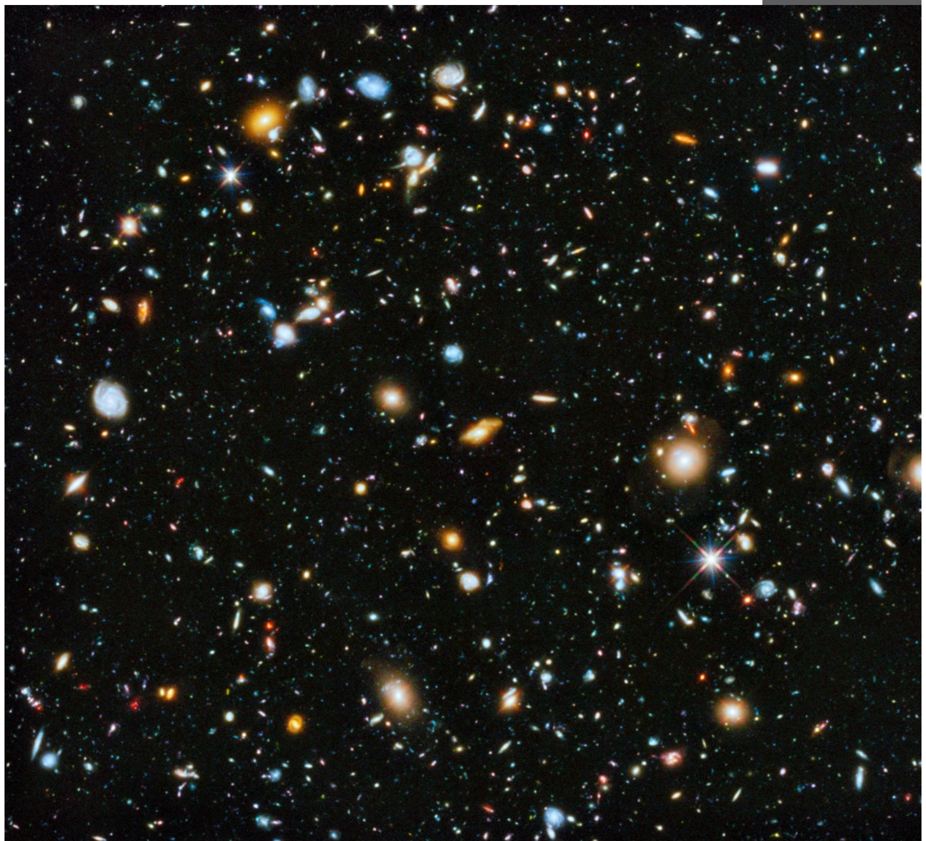

Image: NASA, ESA, H. Teplitz & M. Rafelski (IPAC/Caltech), A. Koekemoer (STScI), R. Windhorst (Arizona State University), & Z. Levay (STScI).

Current knowledge of the universe

Big bang theory

- Alexander Friedman, in 1922, and Georges Lemaître, in 1927, used Einstein's theory of general relativity to propose an **expanding model for the universe**.
- In 1929, **Edwin Hubble** concluded that galaxies are drifting apart. This is an important **observational evidence** consistent with the hypothesis of an **expanding universe**.
- In 1948, **George Gamow** concluded, by reversing the observed expansion, that the universe began in an initially very hot, dense state (**big bang theory**).

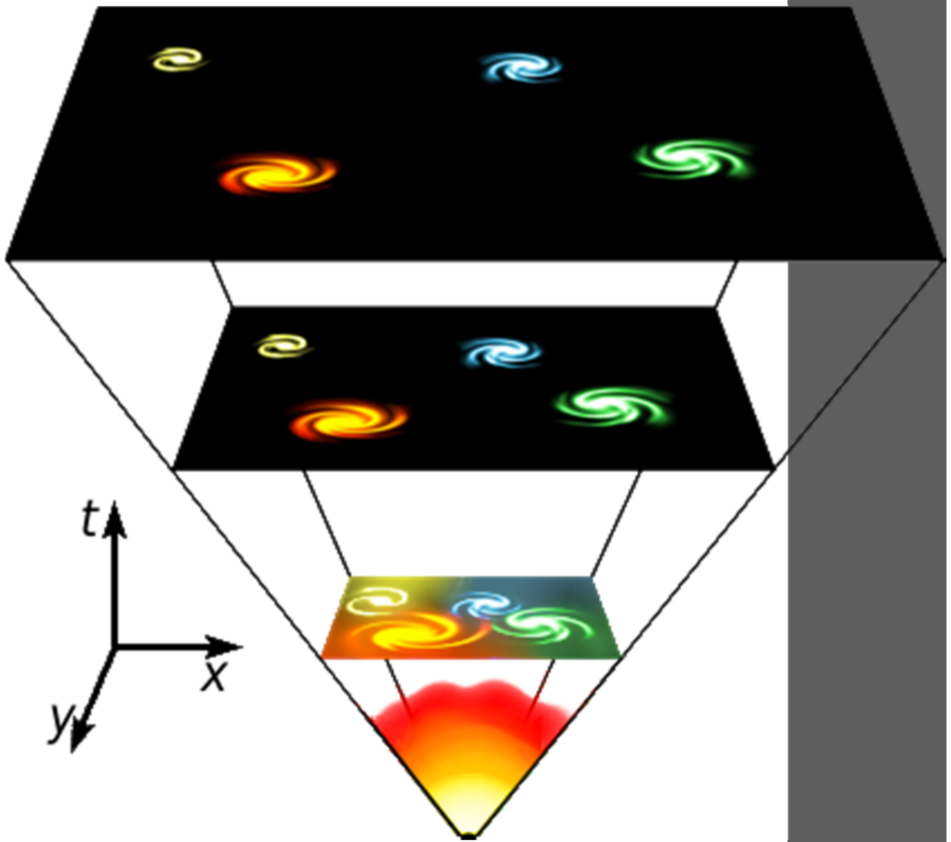

Image: Fredrik

Current knowledge of the universe

Big bang theory

- **Big bang theory** explains that time, space, and matter (i.e., the universe) began **~13 700 million years ago** with the **explosion** of a **cosmic singularity**, where matter was a point of infinite density.

- This explosion generated the **expansion of the universe in all directions**.

- Since the universe began, it has expanded from an extremely small, dense and hot singularity to the enormous, cold, and diffuse universe we see around us today.

https://youtu.be/a9L9-ddwcrE

Current knowledge of the universe

Big bang theory: observational evidence

- The **expansion of the universe** as deduced from Hubble's experimental observations. Extrapolating backwards in time, we can conclude that at some time in the distant past, all matter in the universe must have been contained in a small region of space.

- The **abundances of primordial elements** (hydrogen, helium, deuterium, lithium) are consistent with their creation in the big bang, and not in stars.

- Immediately after big bang, the universe was opaque to electromagnetic radiation. As the universe expanded, it also cooled, and eventually it cooled to the point that electromagnetic radiation traveled freely through the universe without interacting with matter, and constitutes what we observe today as **cosmic microwave background radiation**.