ROYAL
OBSERVATORY
GREENWICH

INTRODUCTION TO ASTRONOMY

Greg Smye-Rumsby - @gregsmyerumsby

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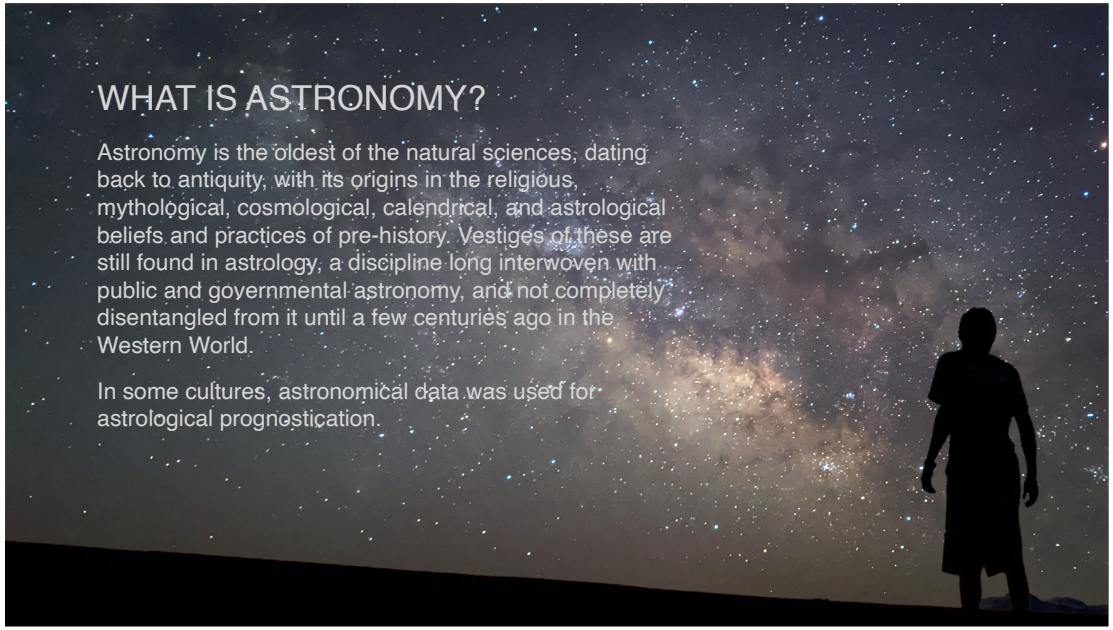
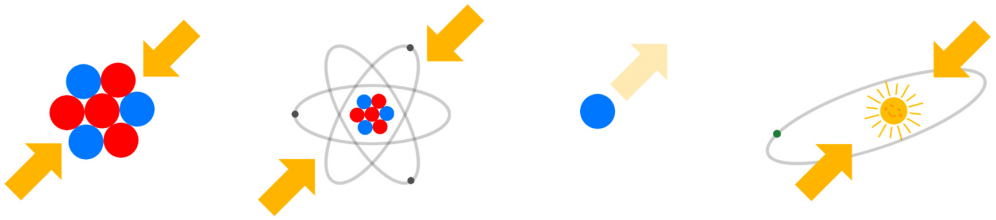
HISTORY

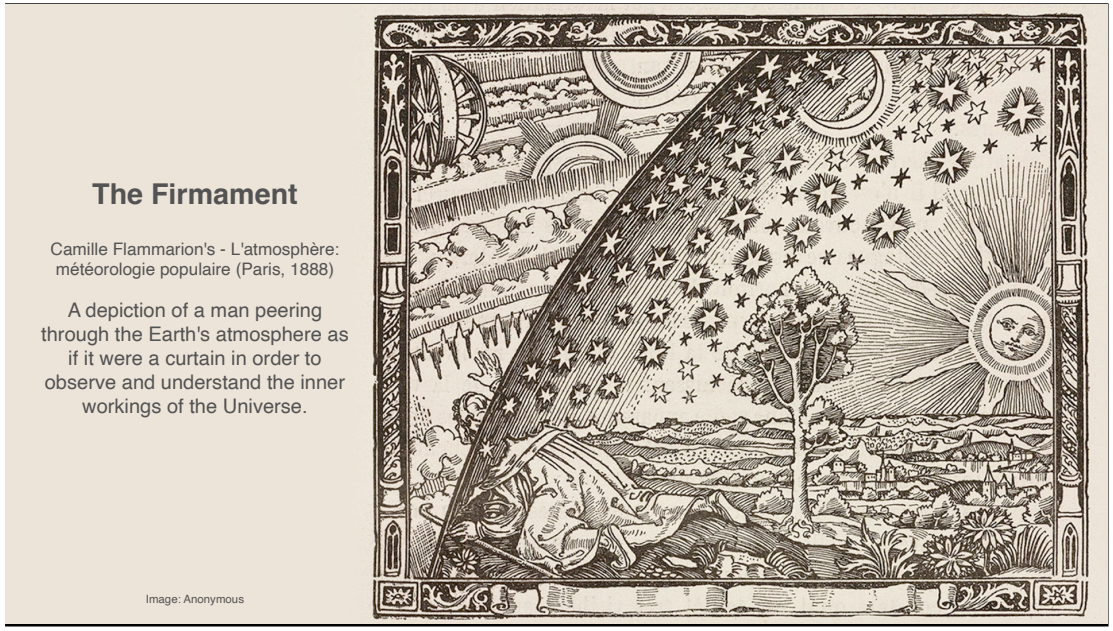

WHAT IS ASTRONOMY?
Astronomy is the oldest of the natural sciences, dating back to antiquity, with its origins in the religious, mythological, cosmological, calendrical, and astrological beliefs and practices of pre-history. Vestiges of these are still found in astrology, a discipline long interwoven with public and governmental astronomy, and not completely disentangled from it until a few centuries ago in the Western World.
In some cultures, astronomical data was used for astrological prognostication.

The Four Fundamental Forces of Nature



Strong Nuclear Force	Electro-magnetic Force	Weak Nuclear Force	Gravity
The force that holds the nucleus of an atom together	How both moving and stationary charged particles interact (Lorentz Force)	Allows protons to turn into neutrons and vice versa through beta decay	The fundamental interaction which causes mutual attraction between all things with mass or energy
Strength = 1	**Strength = 1/137**	**Strength = 10^{-6}**	**Strength = 6×10^{-39}**


GRAVITY
… it drives everything



The Flammarion engraving is a wood engraving by an unknown artist that first appeared in Camille Flammarion's L'atmosphère: météorologie populaire (1888). The image depicts a man crawling under the edge of the sky, depicted as if it were a solid hemisphere, to look at the mysterious Empyrean beyond. The caption underneath the engraving (not shown here) translates to "A medieval missionary tells that he has found the point where heaven and Earth meet..."

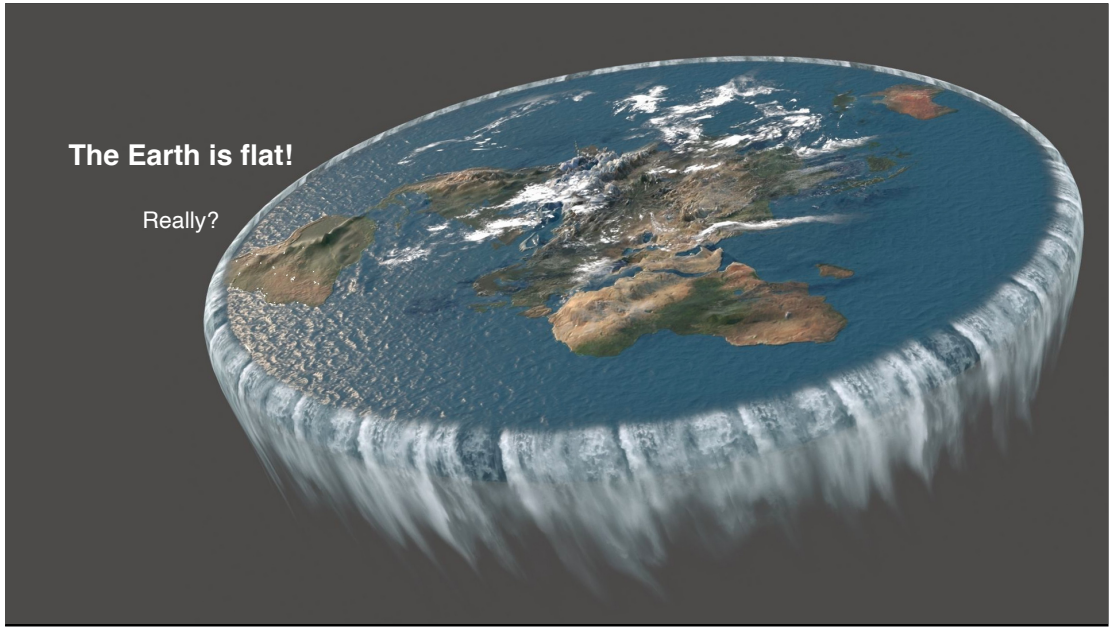
https://en.wikipedia.org/wiki/Firmament

In biblical cosmology, the firmament is the vast solid dome created by God on the second day to divide the primal sea (called tehom) into upper and lower portions so that the dry land could appear:

Then God said, “Let there be a firmament in the midst of the waters, and let it divide the waters from the waters.” Thus God made the firmament, and divided the waters which were under the firmament from the waters which were above the firmament; and it was so. And God called the firmament Heaven. So the evening and the morning were the second day.

The Earth is flat!

Really?



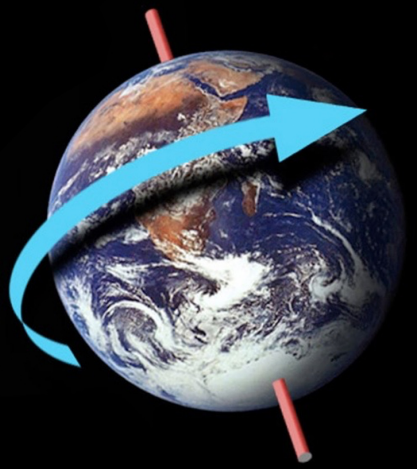
https://en.wikipedia.org/wiki/Flat_Earth

Heraclides Ponticus (Herakleides)

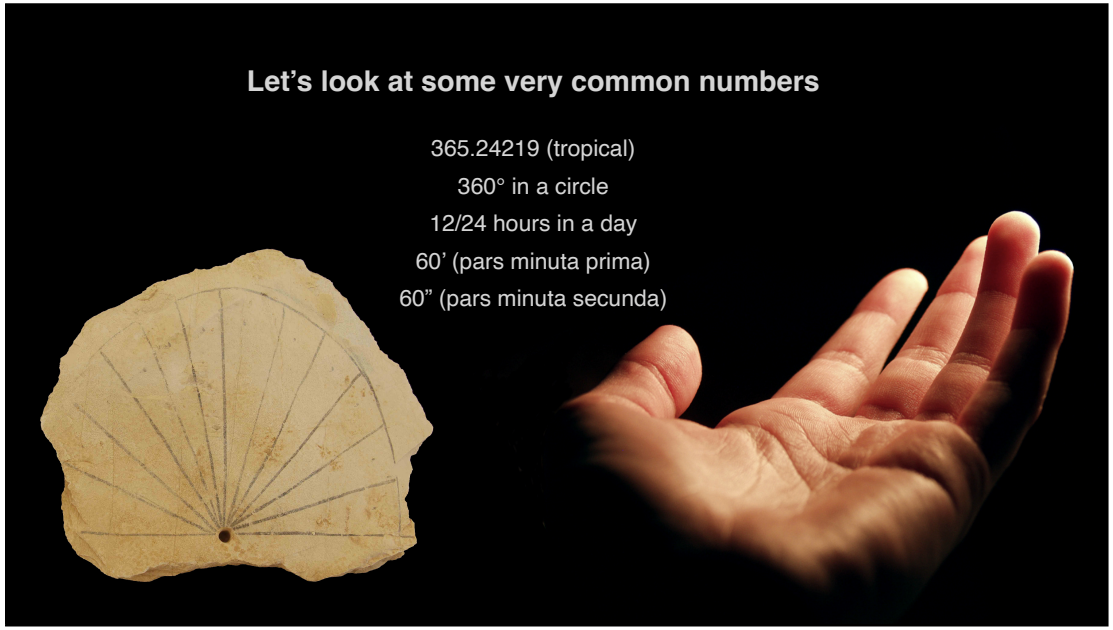
c. 390 - c. 310 BC

Heraclides proposed that the apparent daily motion of the stars was created by the rotation of the Earth on its axis once a day. This view contradicted the accepted Aristotelian model of the universe, which said that the Earth was fixed and that the stars and planets in their respective spheres might also be fixed.

Simplicius says that Heraclides proposed that the irregular movements of the planets can be explained if the Earth moves while the Sun stays still.



https://en.wikipedia.org/wiki/Heraclides_Ponticus



https://pumas.nasa.gov/files/04_21_97_1.pdf

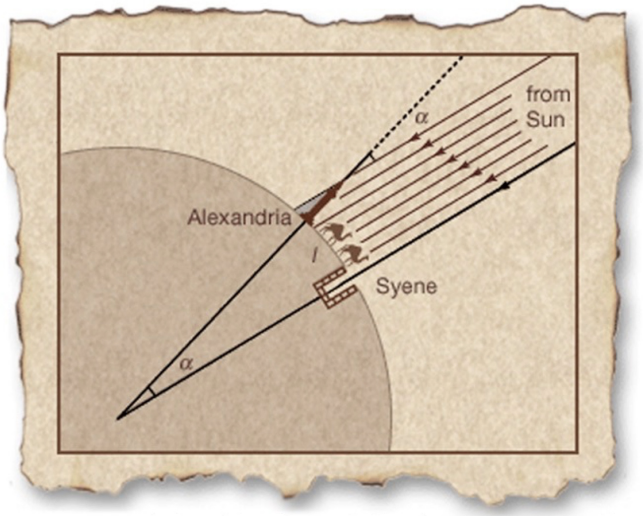
https://www.scientificamerican.com/article/experts-time-division-days-hours-minutes/#:~:text=In%20his%20treatise%20Almagest%20(circa,subdivided%20into%2060%20smaller%20parts.

THE DIVISION of the hour into 60 minutes and of the minute into 60 seconds comes from the Babylonians who used a sexagesimal (counting in 60s) system for mathematics and astronomy. They derived their number system from the Sumerians who were using it as early as 3500 BC.

The first division, partes minutae primae, or first minute, became known simply as the "minute." The second segmentation, partes minutae secundae, or "second minute," became known as the second.

Eratosthenes of Cyrene
c.275-192

On the summer solstice at local noon in the Ancient Egyptian city of Swenet (Aswan) on the Tropic of Cancer, the sun would appear at the zenith, directly overhead. Eratosthenes knew, from measurement, that in his hometown of Alexandria, the angle of elevation of the sun would be 1/50 of a full circle (7°12') south of the zenith at the same time. Assuming that Alexandria was due north of Swenet he concluded that the distance from Alexandria to Syene must be 1/50 of the total circumference of the earth - 800 km.



His calculations led him to the conclusion that the Earth's circumference must be about 39,690 km, an error of less than 1%.

https://en.wikipedia.org/wiki/Eratosthenes

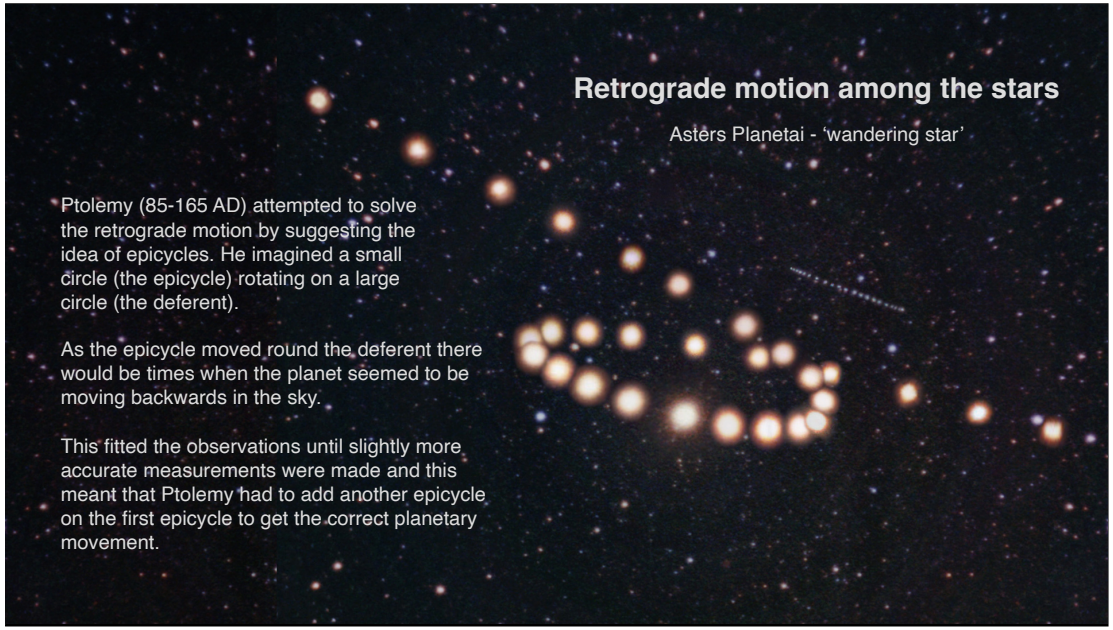
The Astrolabe

There is a German astrolabe that is similar to this one, made in Hamburg in 1608 that may have served as a model.

The shape of the pierced disk (rete) is a map of the sky and the arrangement on the back are reminiscent of late-medieval astrolabes; but the form of the stamped Arabic numbers and the letter shapes of the Latin alphabet are clearly not medieval.

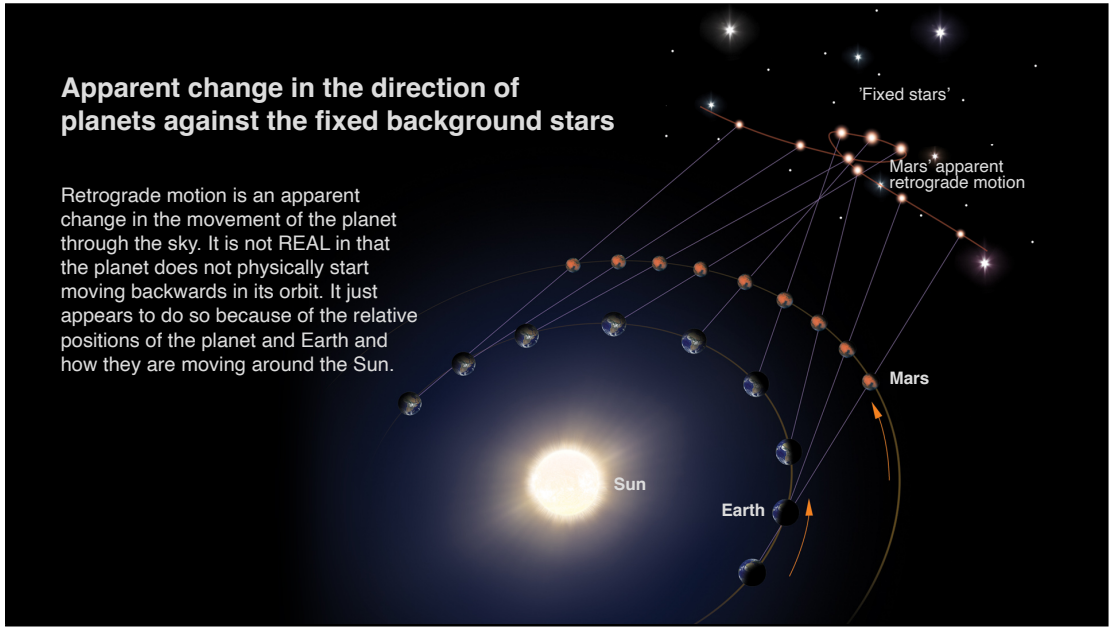
The rim (mater) consists of a thin plate, without a thickened limb. Three lobes spring from it, with the larger, middle one pierced so that a ring can run through it, which, in turn, holds the suspension ring. The design of the rete is very simple: a straight equinoctial and solstitial bar, with the circles of the ecliptic and the equator. On the back of the instrument is a combined scale for degrees and the zodiac and a calendrical scale. The rest of the back is divided into two halves: the upper half shows the arcs for unequal hours and the lower half contains a shadow square.

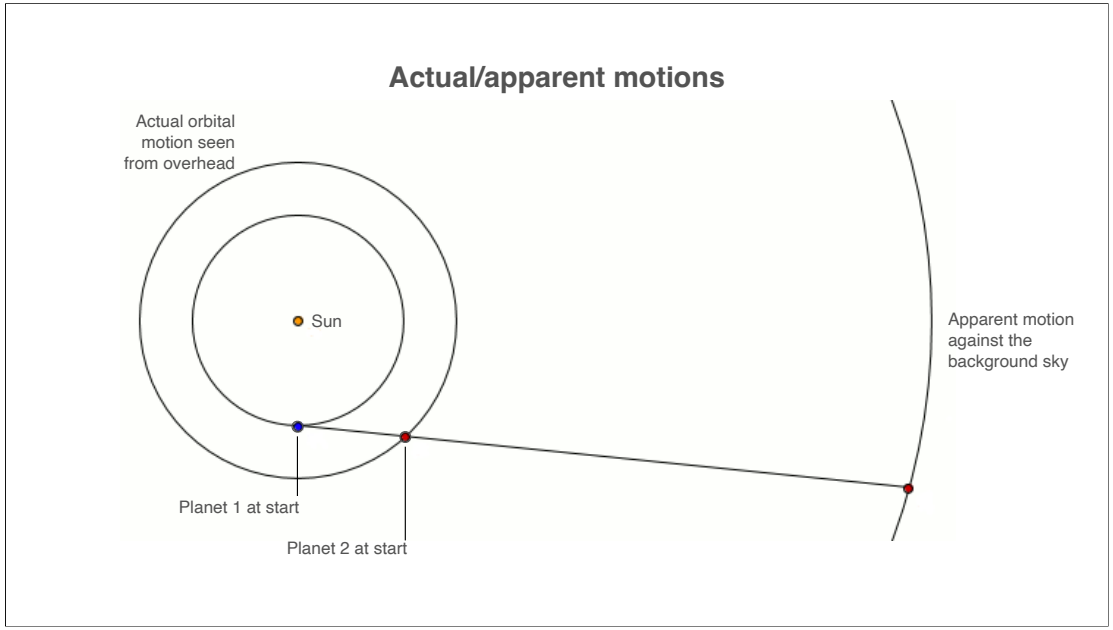
https://en.wikipedia.org/wiki/Eratosthenes

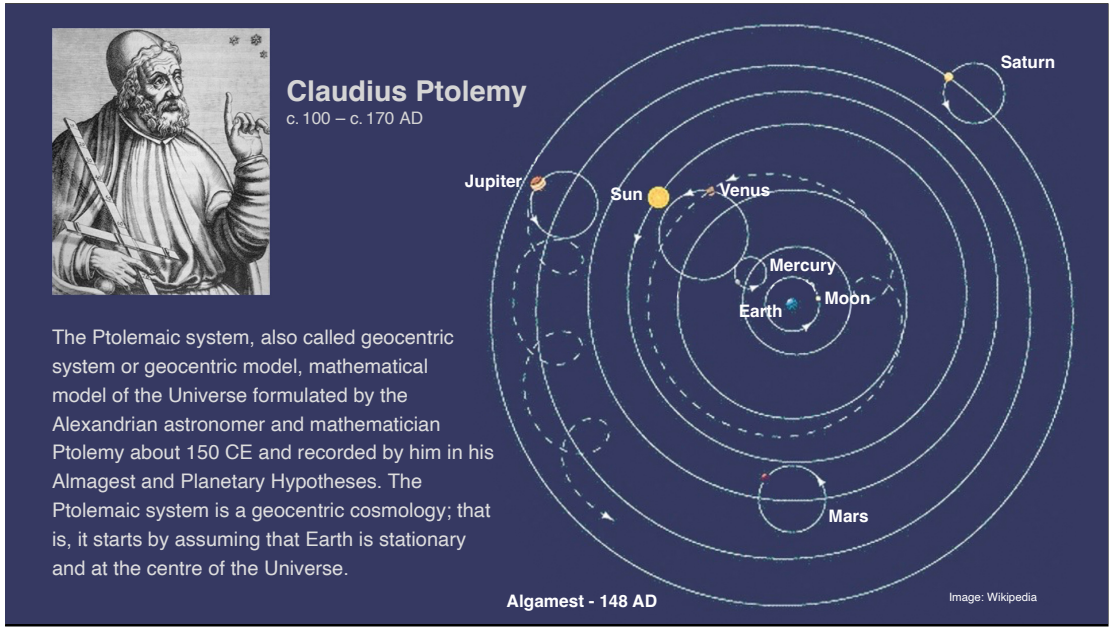

Retrograde motion among the stars
Asters Planetai - ‘wandering star’
Ptolemy (85-165 AD) attempted to solve the retrograde motion by suggesting the idea of epicycles. He imagined a small circle (the epicycle) rotating on a large circle (the deferent).
As the epicycle moved round the deferent there would be times when the planet seemed to be moving backwards in the sky.
This fitted the observations until slightly more accurate measurements were made and this meant that Ptolemy had to add another epicycle on the first epicycle to get the correct planetary movement.

Apparent change in the direction of planets against the fixed background stars

Retrograde motion is an apparent change in the movement of the planet through the sky. It is not REAL in that the planet does not physically start moving backwards in its orbit. It just appears to do so because of the relative positions of the planet and Earth and how they are moving around the Sun.




Actual/apparent motions
Actual orbital motion seen from overhead
Sun
Apparent motion against the background sky
Planet 1 at start
Planet 2 at start



https://en.wikipedia.org/wiki/Geocentric_model

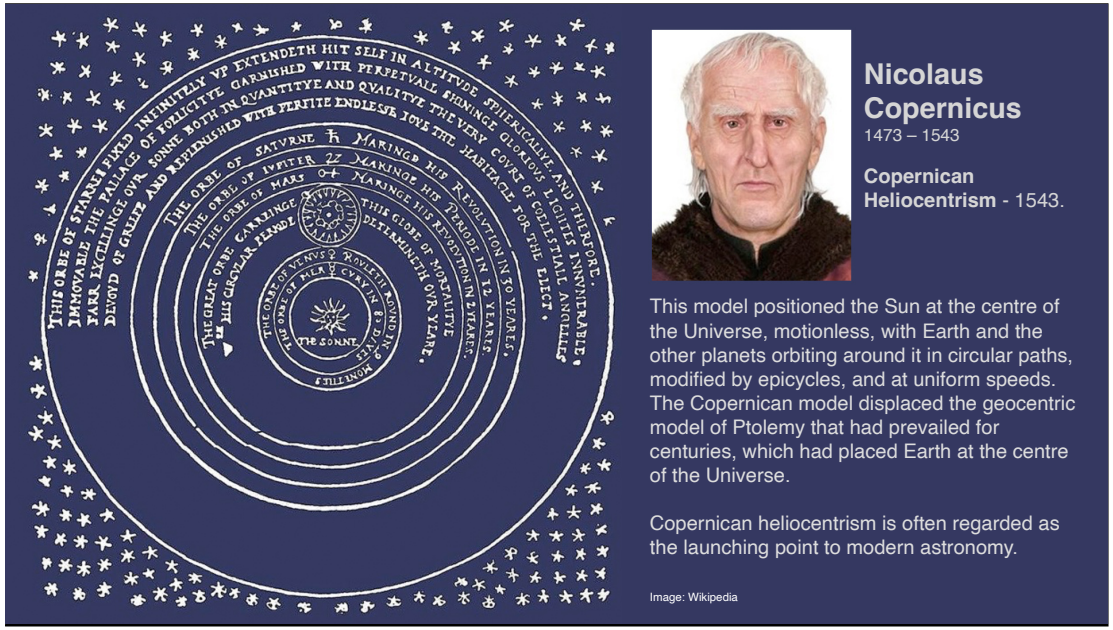
In astronomy, the geocentric model (also known as geocentrism, often exemplified specifically by the Ptolemaic system) is a superseded description of the Universe with Earth at the center. Under the geocentric model, the Sun, Moon, stars, and planets all orbited Earth. The geocentric model was the predominant description of the cosmos in many ancient civilizations, such as those of Aristotle in Classical Greece and Ptolemy in Roman Egypt.

Two observations supported the idea that Earth was the center of the Universe:

First, from anywhere on Earth, the Sun appears to revolve around Earth once per day. While the Moon and the planets have their own motions, they also appear to revolve around Earth about once per day. The stars appeared to be fixed on a celestial sphere rotating once each day about an axis through the geographic poles of Earth.
Second, Earth seems to be unmoving from the perspective of an earthbound observer; it feels solid, stable, and stationary.
Ancient Greek, ancient Roman, and medieval philosophers usually combined the geocentric model with a spherical Earth, in contrast to the older flat-Earth model implied in some mythology. The ancient Jewish Babylonian uranography pictured a flat Earth with a dome-

shaped, rigid canopy called the firmament placed over it. However, the Greek astronomer and mathematician Aristarchus of Samos (c. 310 – c. 230 BC) developed a heliocentric model placing all of the then-known planets in their correct order around the Sun. The ancient Greeks believed that the motions of the planets were circular, a view that was not challenged in Western culture until the 17th century, when Johannes Kepler postulated that orbits were heliocentric and elliptical (Kepler's first law of planetary motion). In 1687 Newton showed that elliptical orbits could be derived from his laws of gravitation.

The astronomical predictions of Ptolemy's geocentric model, developed in the 2nd century CE, served as the basis for preparing astrological and astronomical charts for over 1500 years. The geocentric model held sway into the early modern age, but from the late 16th century onward, it was gradually superseded by the heliocentric model of Copernicus (1473-1543), Galileo (1564-1642), and Kepler (1571-1630). There was much resistance to the transition between these two theories. Some felt that a new, unknown theory could not subvert an accepted consensus for geocentrism.



Nicolaus Copernicus

1473 – 1543

Copernican Heliocentrism - 1543.

This model positioned the Sun at the centre of the Universe, motionless, with Earth and the other planets orbiting around it in circular paths, modified by epicycles, and at uniform speeds. The Copernican model displaced the geocentric model of Ptolemy that had prevailed for centuries, which had placed Earth at the centre of the Universe.

Copernican heliocentrism is often regarded as the launching point to modern astronomy.

Image: Wikipedia

https://en.wikipedia.org/wiki/Copernican_heliocentrism

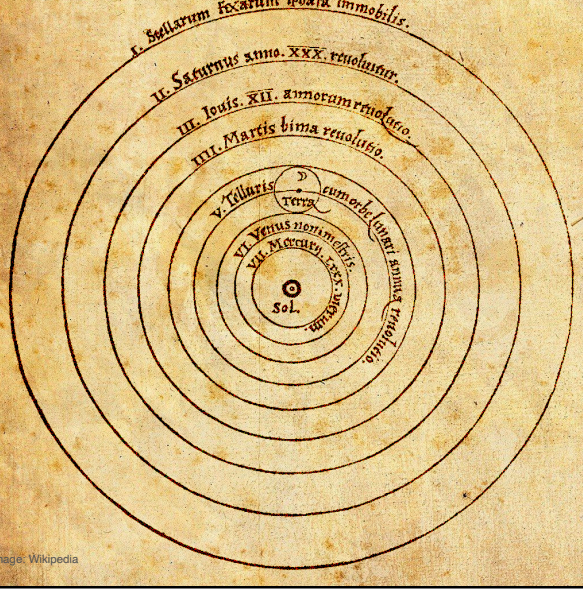


Image: Wikipedia

Heliocentric Model

Immobile sphere of fixed stars

Saturn completes one revolution every 30 years

One revolution of Jupiter every 12 years

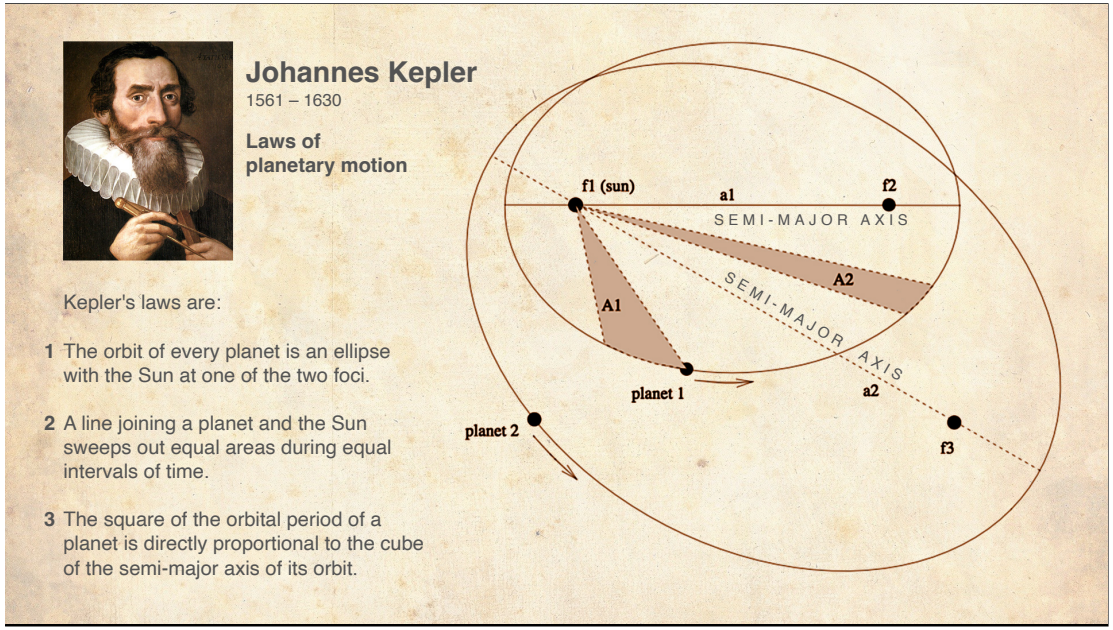
Biannual revolution of Mars

Annual revolution of Earth and sphere of Moon

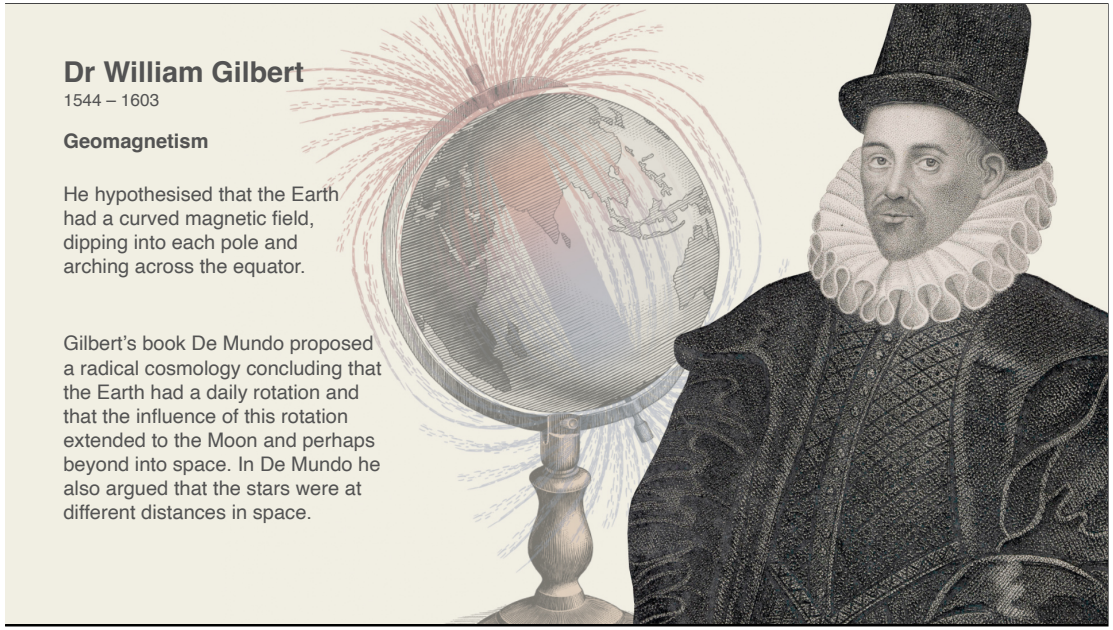
Venus every 7 1/2 months

Mercury in 88 days

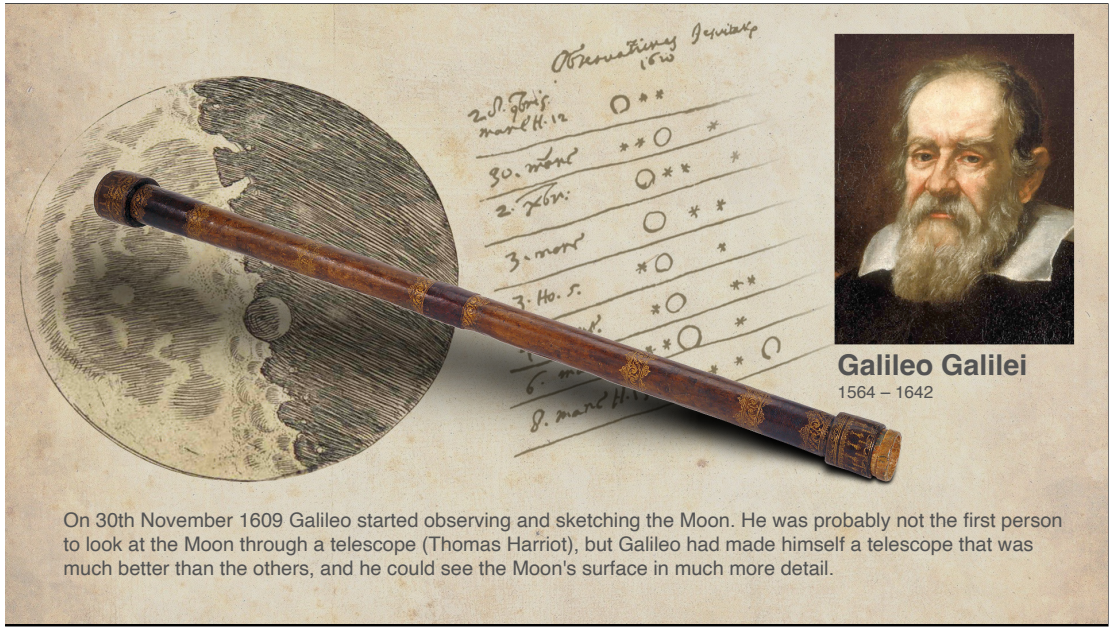
Sun - stands still at the centre



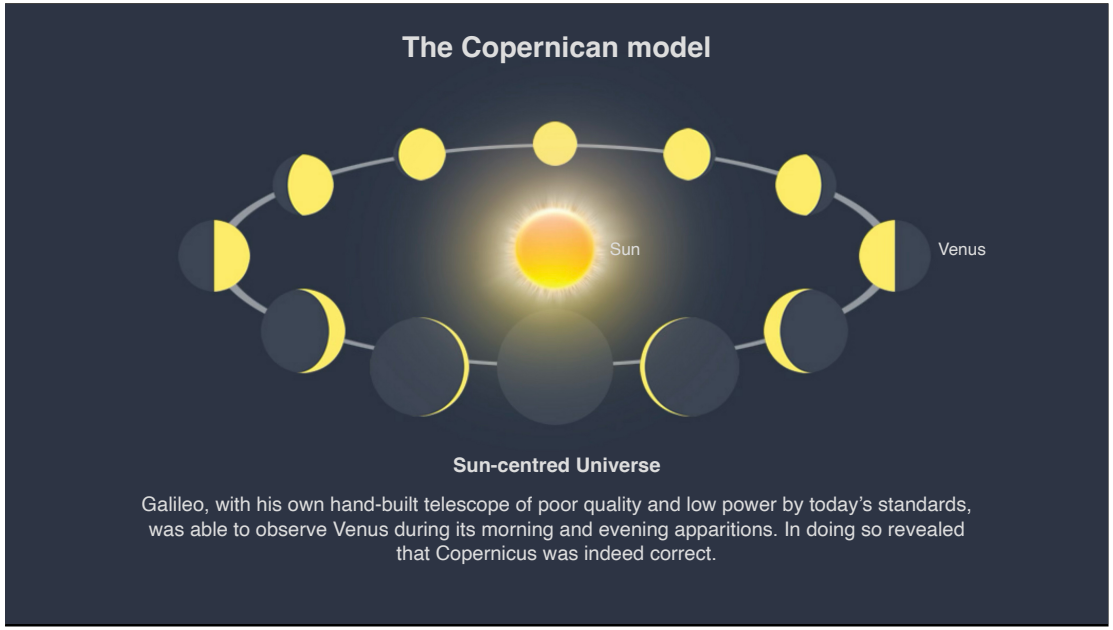
https://en.wikipedia.org/wiki/Johannes_Kepler



https://en.wikipedia.org/wiki/William_Gilbert_(physicist)



https://en.wikipedia.org/wiki/Galileo_Galilei



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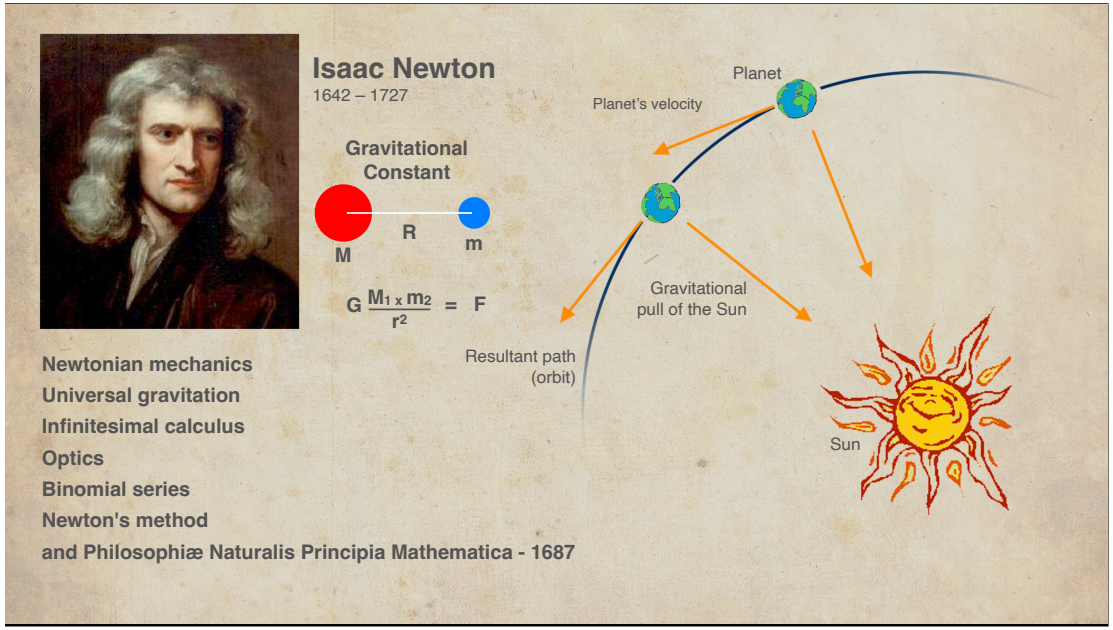
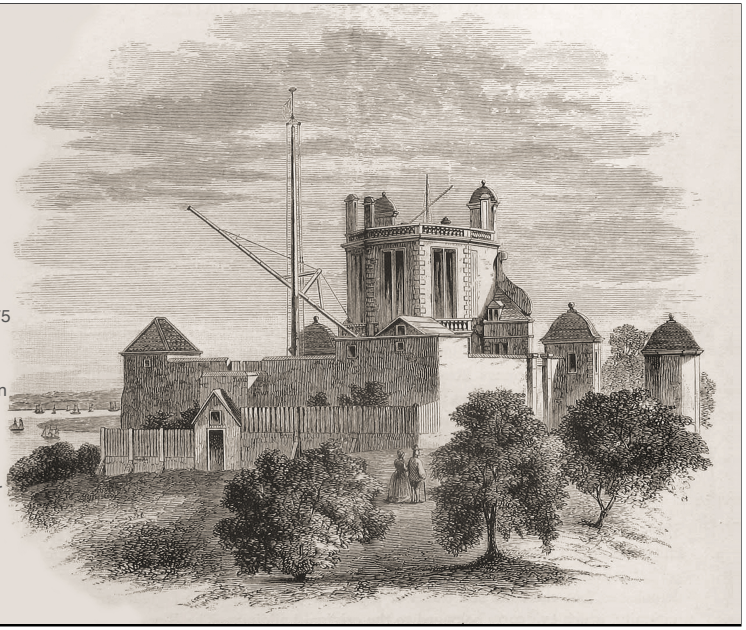


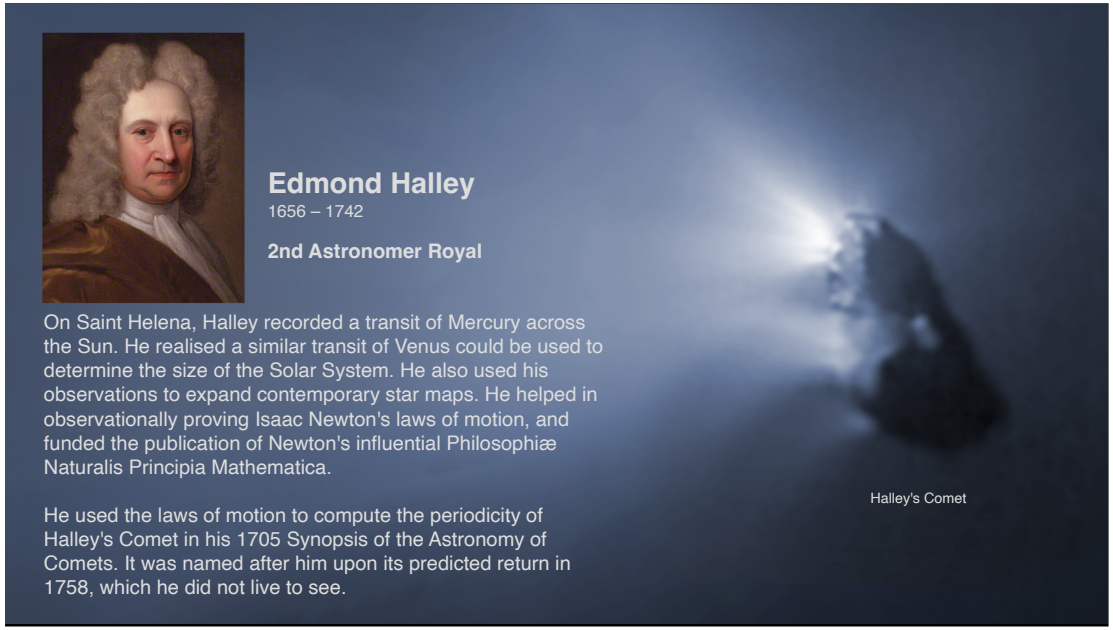
https://en.wikipedia.org/wiki/Isaac_Newton

Royal Observatory

1675 - 1998

The Royal Observatory, Greenwich is an observatory situated in Greenwich Park overlooking the River Thames. It played a major role in the history of astronomy and navigation, and because the Prime Meridian passed through it, it gave its name to Greenwich Mean Time. The observatory was commissioned in 1675 by King Charles II, with the foundation stone being laid on 10 August. The old hilltop site of Greenwich Castle was chosen by Sir Christopher Wren as Greenwich Park was a royal estate. John Flamsteed was the first Astronomer Royal. The building was completed in the summer of 1676. The building was often called "Flamsteed House", in reference to its first occupant.



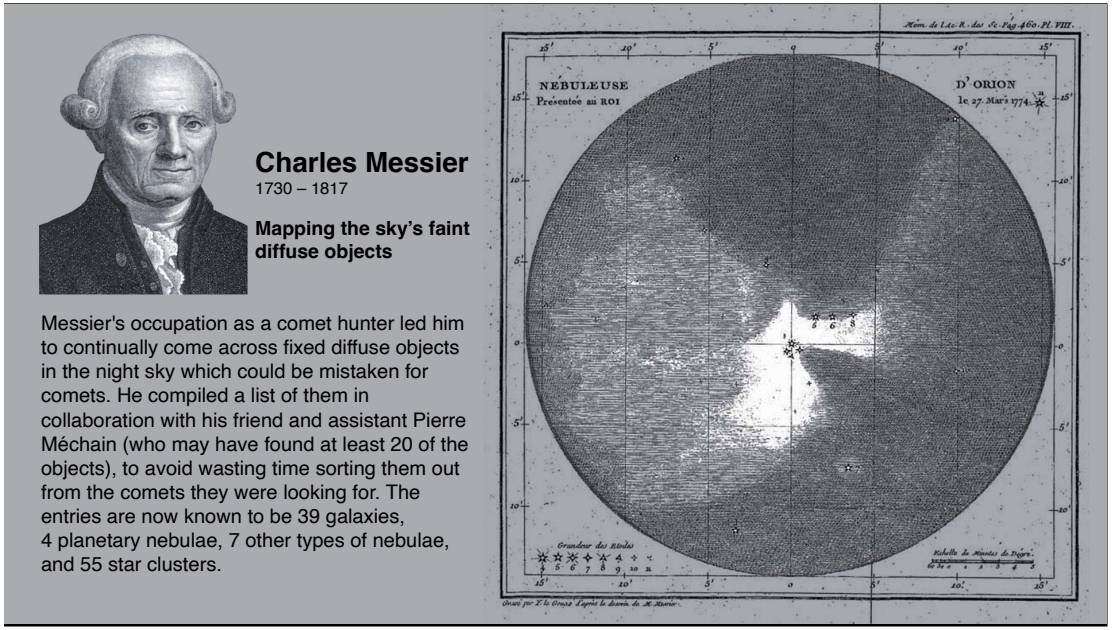


https://en.wikipedia.org/wiki/Edmond_Halley

Edmond[1] (or Edmund[2]) Halley, FRS (/ˈhæli/;[3][4] 8 November [O.S. 29 October] 1656 – 25 January 1742 [O.S. 14 January 1742]) was an English astronomer, geophysicist, mathematician, meteorologist, and physicist. He was the second Astronomer Royal in Britain, succeeding John Flamsteed in 1720.[5]

From an observatory he constructed on Saint Helena,[6] Halley recorded a transit of Mercury across the Sun. He realised a similar transit of Venus could be used to determine the size of the Solar System.[7] He also used his observations to expand contemporary star maps. He aided in observationally proving Isaac Newton's laws of motion, and funded the publication of Newton's influential Philosophiæ Naturalis Principia Mathematica.[8] From his September 1682 observations, he used the laws of motion to compute the periodicity of Halley's Comet in his 1705 Synopsis of the Astronomy of Comets.[9][10] It was named after him upon its predicted return in 1758, which he did not live to see.

Beginning in 1698, he made sailing expeditions and made observations on the conditions of terrestrial magnetism. In 1718, he discovered the proper motion of the "fixed" stars.[8]



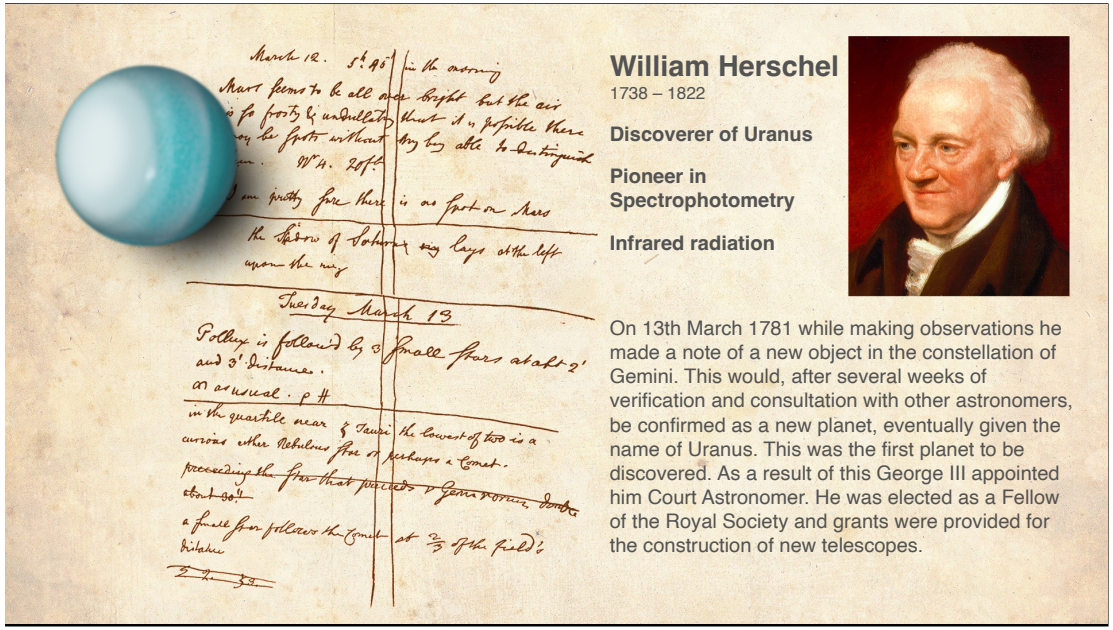
https://en.wikipedia.org/wiki/Charles_Messier

Charles Messier (French: [ʃaʁl me.sje]; 26 June 1730 – 12 April 1817) was a French astronomer. He published an astronomical catalogue consisting of 110 nebulae and faint star clusters, which came to be known as the Messier objects. The purpose of the catalogue was to help astronomical observers distinguish between permanent and transient visually diffuse objects in the sky.

Messier was born in Badonviller in the Lorraine region of France, the tenth of twelve children of Françoise B. Grandblaise and Nicolas Messier, a Court usher. Six of his brothers and sisters died while young, and his father died in 1741. Charles' interest in astronomy was stimulated by the appearance of the great six-tailed comet in 1744 and by an annular solar eclipse visible from his hometown on 25 July 1748.

In 1751, Messier entered the employ of Joseph Nicolas Delisle, the astronomer of the French Navy, who instructed him to keep careful records of his observations. Messier's first documented observation was that of the Mercury transit of 6 May 1753, followed by his observations journals at Cluny Hotel and at the French Navy observatories.

In 1764, Messier was made a fellow of the Royal Society; in 1769, he was elected a foreign member of the Royal Swedish Academy of Sciences; and on 30 June 1770, he was elected to the French Academy of Sciences.

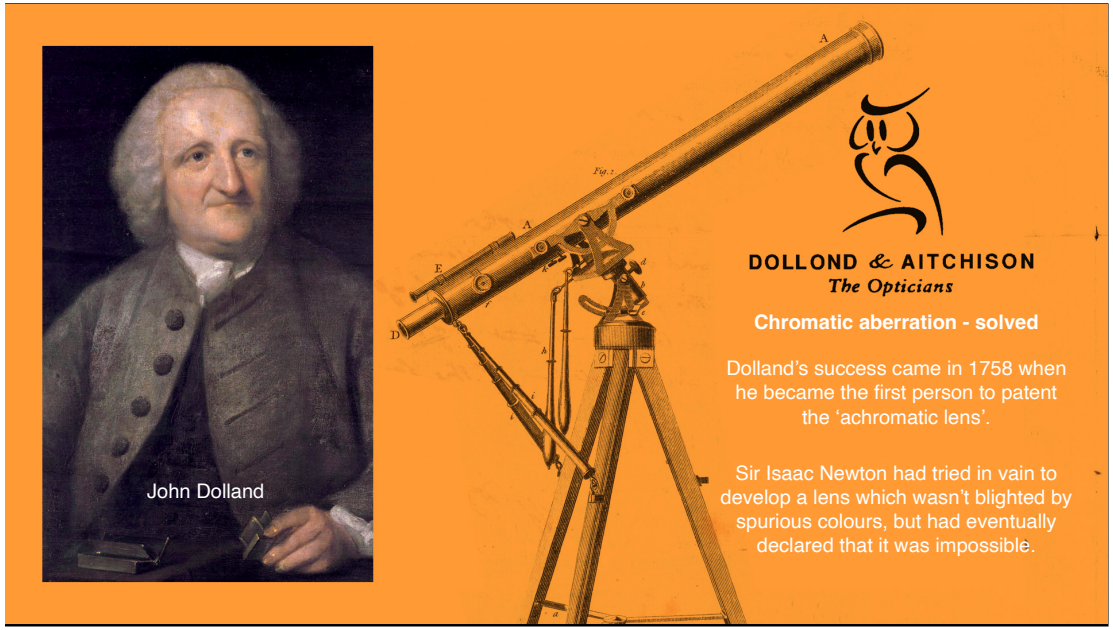


https://en.wikipedia.org/wiki/William_Herschel

Frederick William Herschel[1] KH, FRS German (15 November 1738 – 25 August 1822) was a German-born British astronomer and composer of music. He frequently collaborated with his younger sister and fellow astronomer Caroline Lucretia Herschel (1750–1848). Born in the Electorate of Hanover, William Herschel followed his father into the military band of Hanover, before emigrating to Great Britain in 1757 at the age of nineteen.

Herschel constructed his first large telescope in 1774, after which he spent nine years carrying out sky surveys to investigate double stars. Herschel published catalogues of nebulae in 1802 (2,500 objects) and in 1820 (5,000 objects). The resolving power of the Herschel telescopes revealed that many objects called nebulae in the Messier catalogue were actually clusters of stars. On 13 March 1781 while making observations he made note of a new object in the constellation of Gemini. This would, after several weeks of verification and consultation with other astronomers, be confirmed to be a new planet, eventually given the name of Uranus. This was the first planet to be discovered since antiquity, and Herschel became famous overnight. As a result of this discovery, George III appointed him Court Astronomer. He was elected as a Fellow of the Royal Society and grants were provided for the construction of new telescopes.

Herschel pioneered the use of astronomical spectrophotometry, using prisms and temperature measuring equipment to measure the wavelength distribution of stellar spectra. In the course of these investigations, Herschel discovered infrared radiation. Other work included an improved determination of the rotation period of Mars, the discovery that the Martian polar caps vary seasonally, the discovery of Titania and Oberon (moons of Uranus) and Enceladus and Mimas (moons of Saturn). Herschel was made a Knight of the Royal Guelphic Order in 1816. He was the first President of the Royal Astronomical Society when it was founded in 1820. He died in August 1822, and his work was continued by his only son, John Herschel.

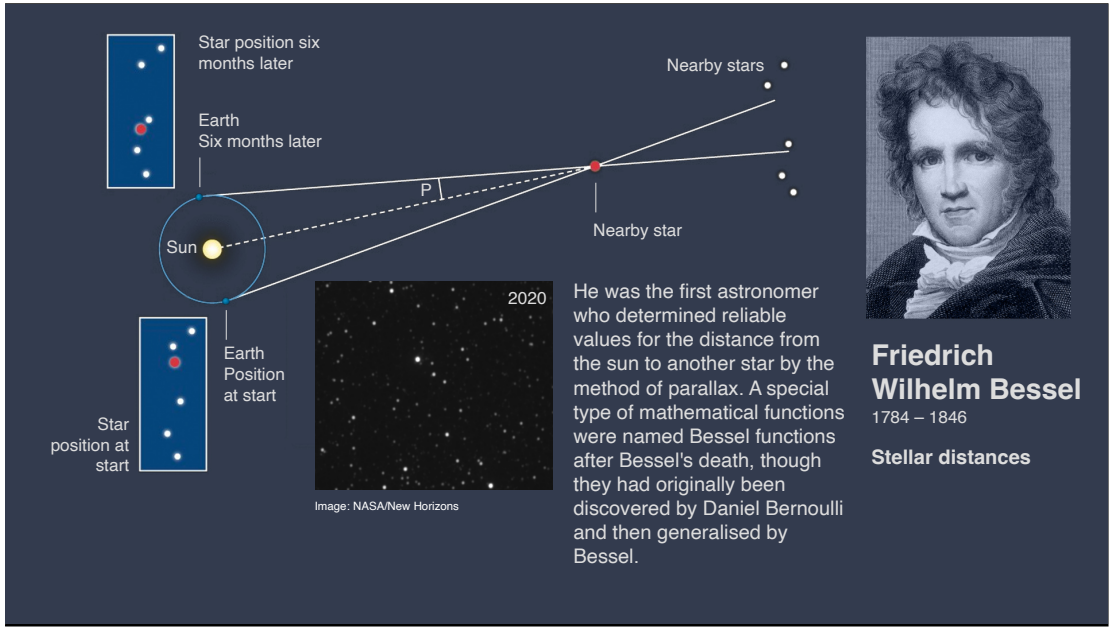


https://en.wikipedia.org/wiki/John_Dollond

https://en.wikipedia.org/wiki/Joseph_von_Fraunhofer#:~:text=By%201814%2C%20Fraunhofer%20had%20invented,of%20refraction%20in%20different%20substances.

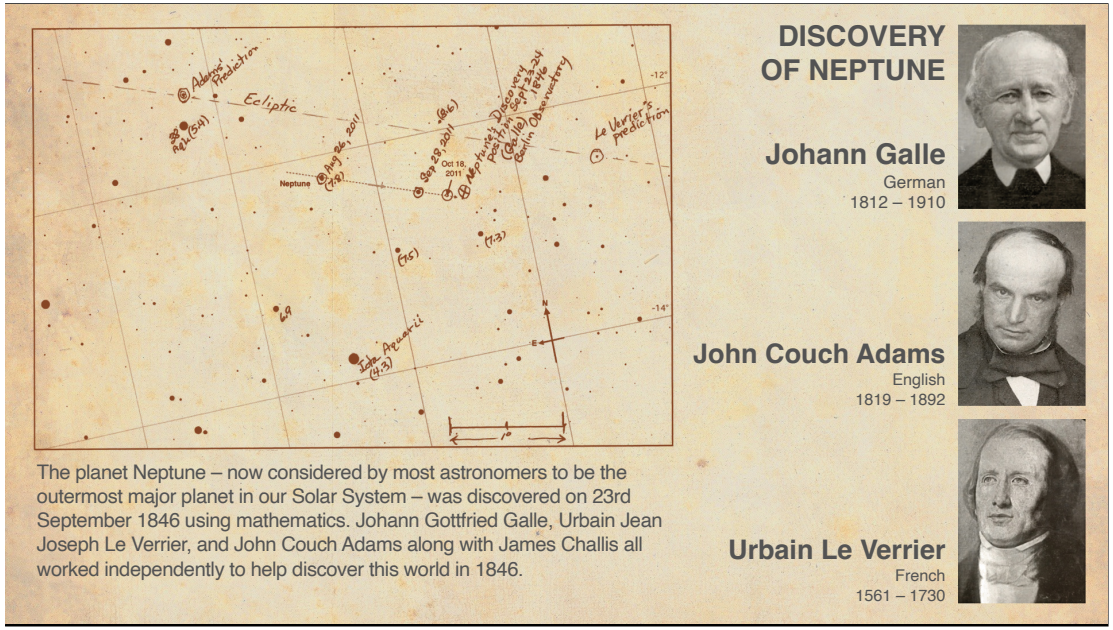
Joseph Ritter von Fraunhofer (6 March 1787 – 7 June 1826) was a Bavarian physicist and optical lens manufacturer. He made optical glass and achromatic telescope objective lenses, invented the spectroscope, and developed diffraction grating. In 1814, he discovered and studied the dark absorption lines in the spectrum of the sun now known as Fraunhofer lines.

The German research organisation Fraunhofer Society is named after him and is Europe's biggest Society for the Advancement of Applied Research.



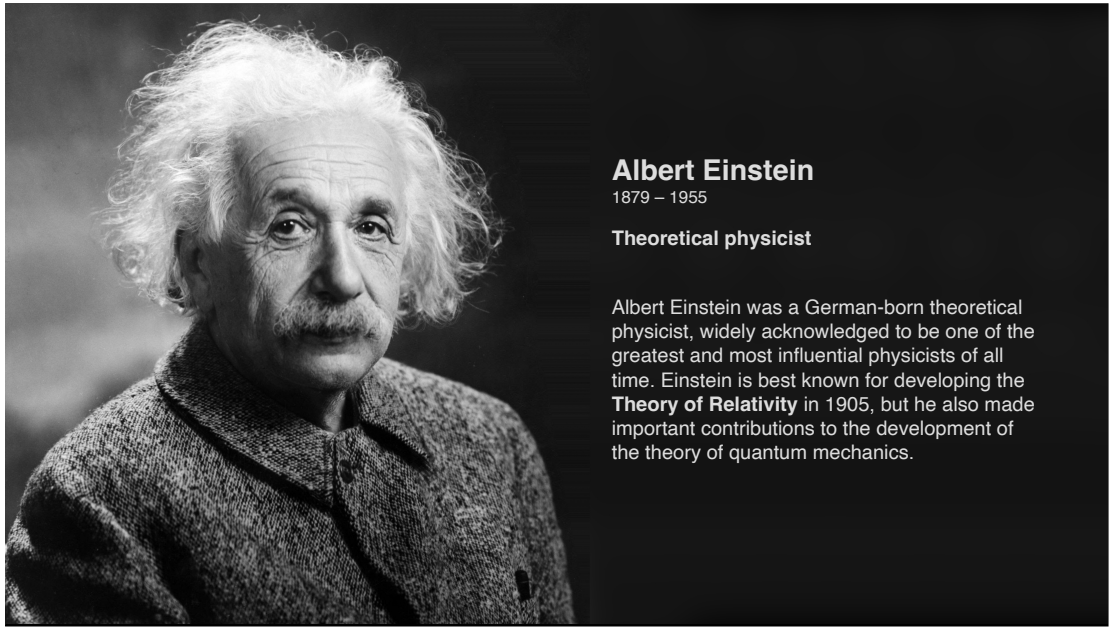
https://en.wikipedia.org/wiki/Friedrich_Bessel

Friedrich Wilhelm Bessel (German: [ˈbɛsl̩]; 22 July 1784 – 17 March 1846) was a German astronomer, mathematician, physicist and geodesist. He was the first astronomer who determined reliable values for the distance from the sun to another star by the method of parallax. A special type of mathematical functions were named Bessel functions after Bessel's death, though they had originally been discovered by Daniel Bernoulli and then generalised by Bessel.

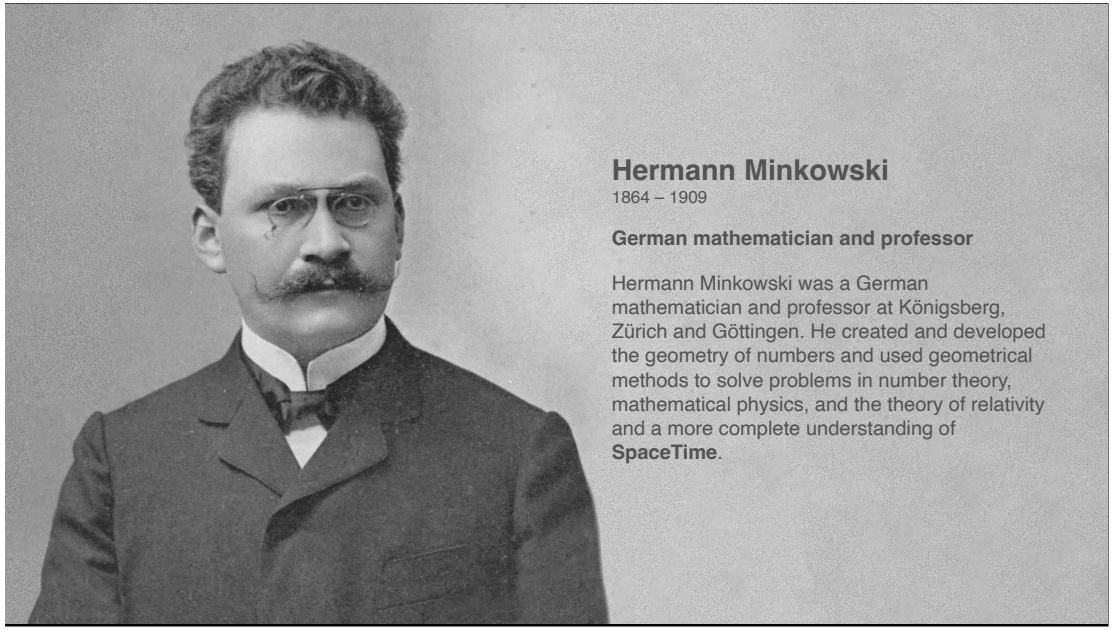


https://en.wikipedia.org/wiki/Discovery_of_Neptune

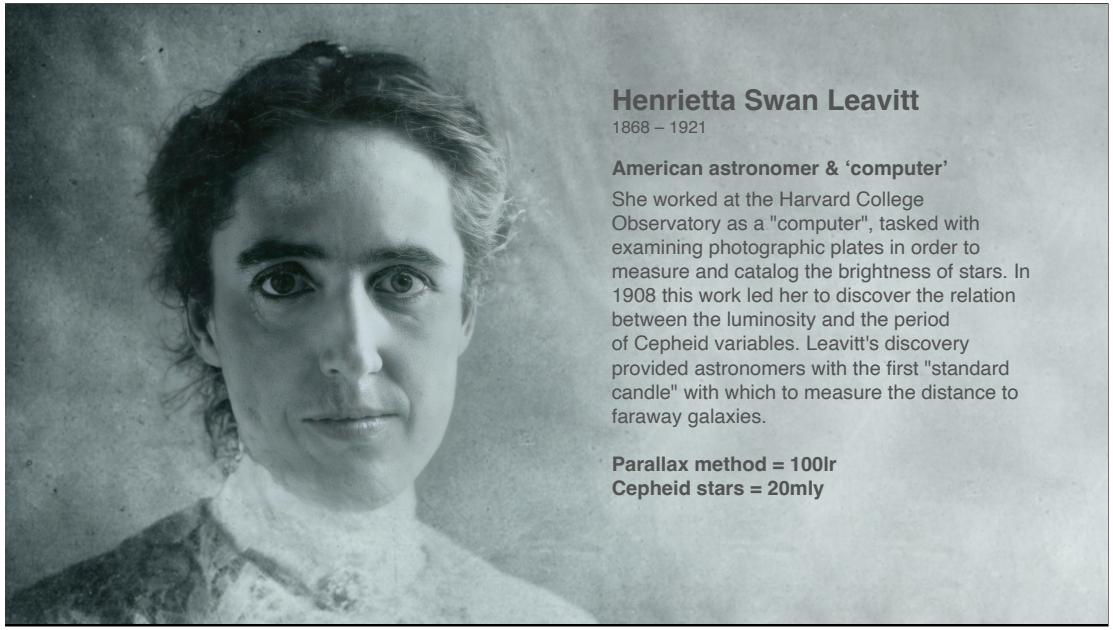
James Challis



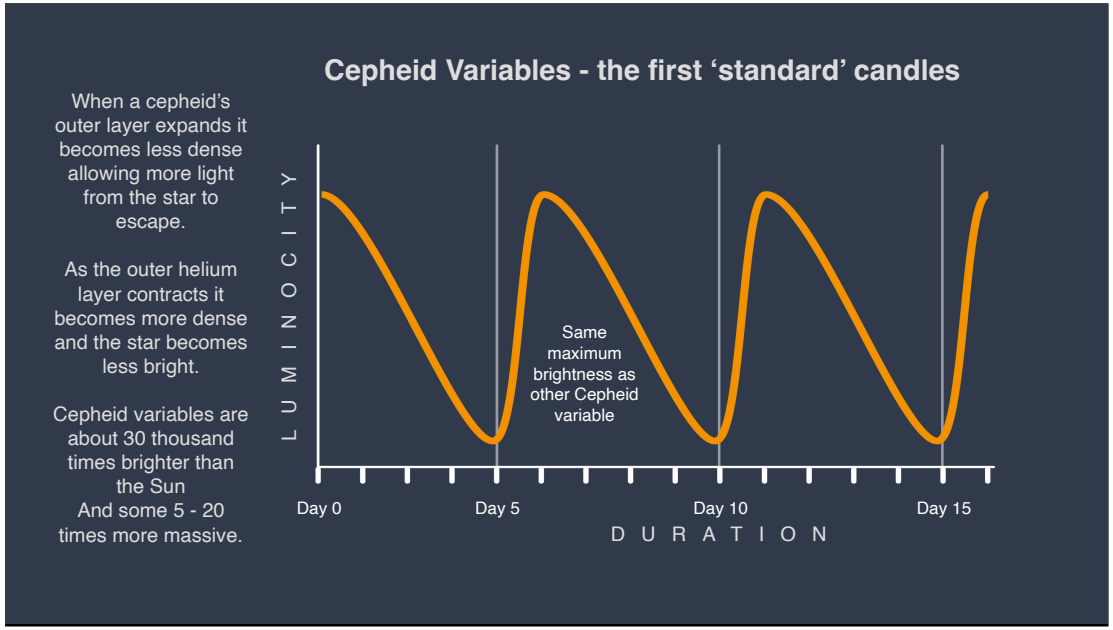
https://en.wikipedia.org/wiki/Albert_Einstein



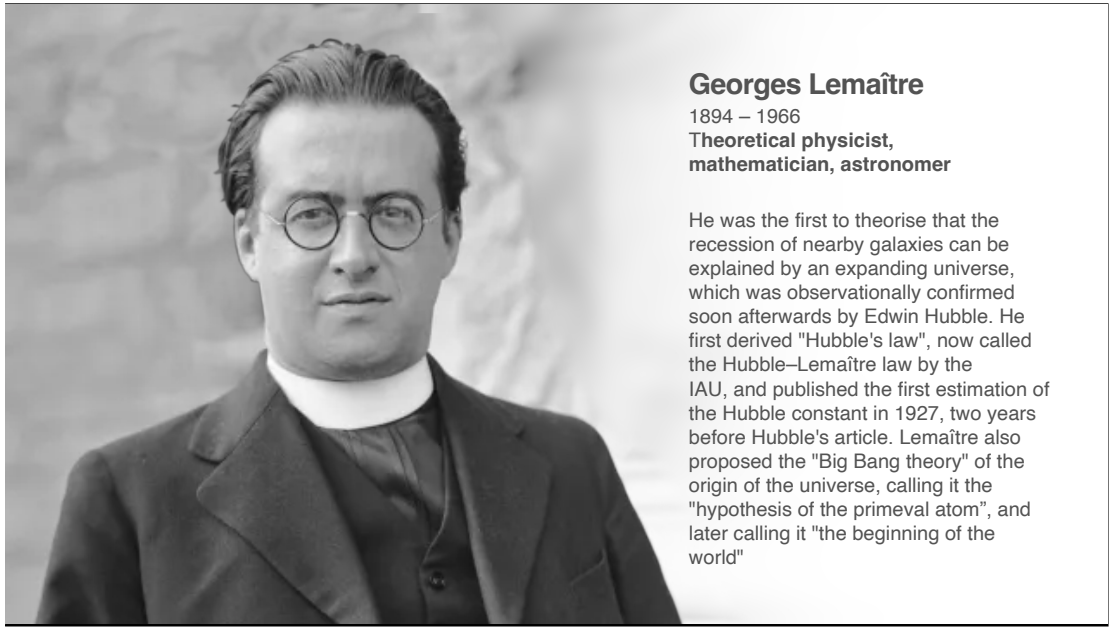
https://en.wikipedia.org/wiki/Hermann_Minkowski



https://en.wikipedia.org/wiki/Henrietta_Swan_Leavitt



https://en.wikipedia.org/wiki/Cepheid_variable

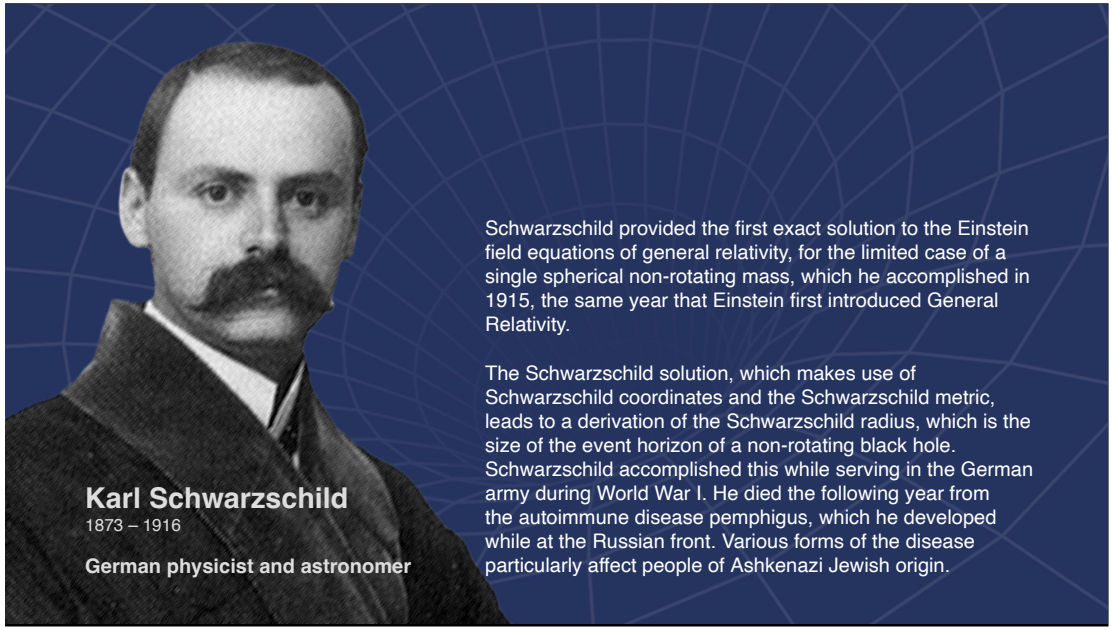


Georges Lemaître

1894 – 1966

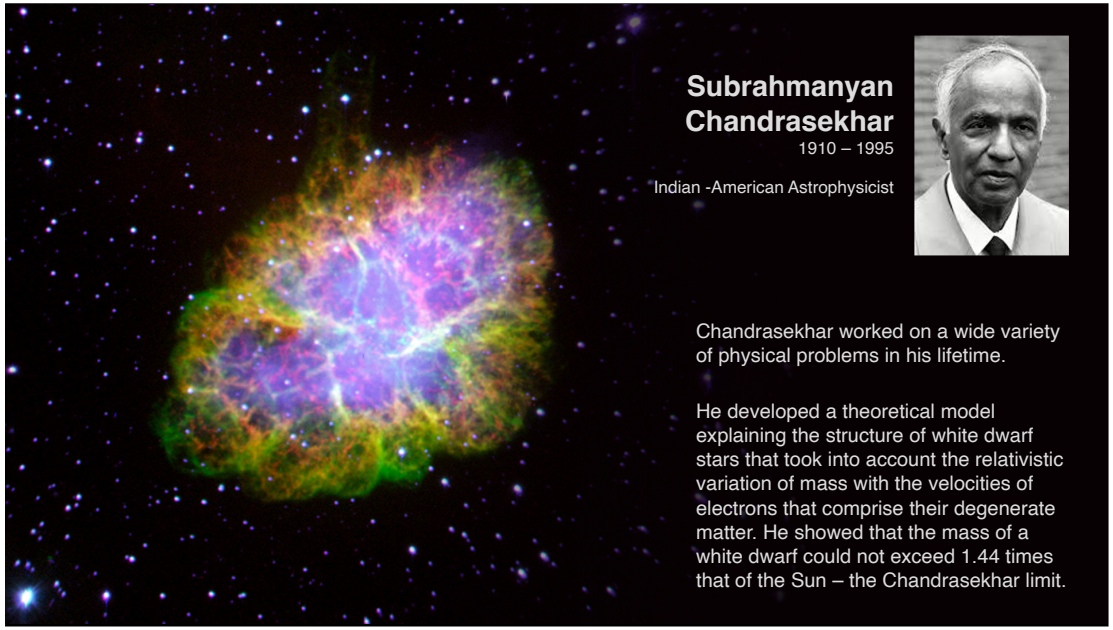
T**heoretical physicist, mathematician, astronomer**

He was the first to theorise that the recession of nearby galaxies can be explained by an expanding universe, which was observationally confirmed soon afterwards by Edwin Hubble. He first derived "Hubble's law", now called the Hubble–Lemaître law by the IAU, and published the first estimation of the Hubble constant in 1927, two years before Hubble's article. Lemaître also proposed the "Big Bang theory" of the origin of the universe, calling it the "hypothesis of the primeval atom", and later calling it "the beginning of the world"

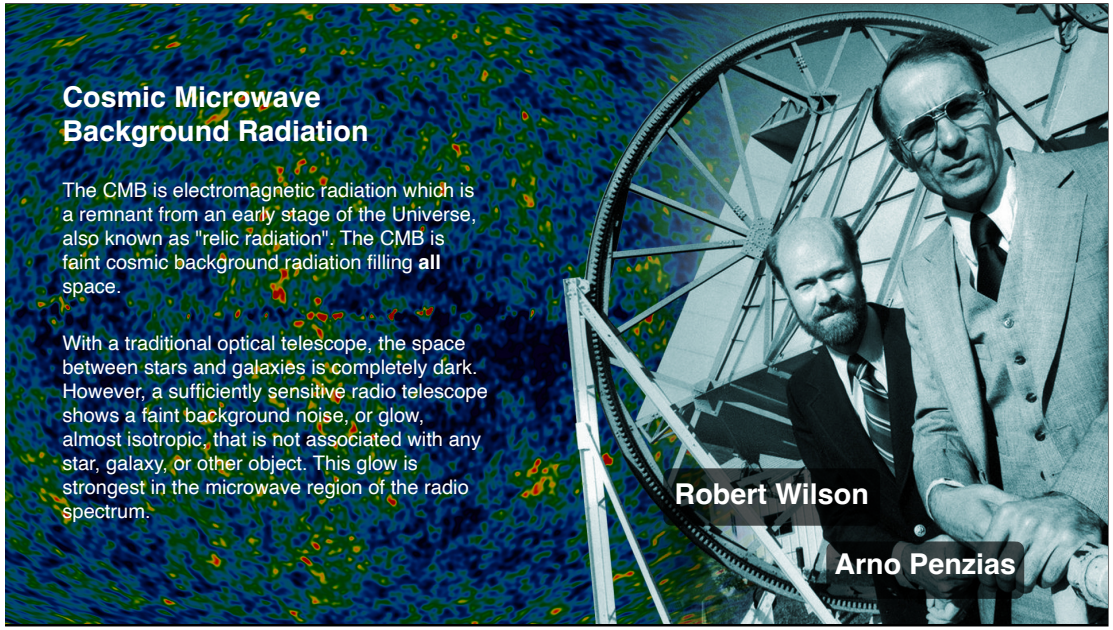


https://en.wikipedia.org/wiki/Karl_Schwarzschild

https://en.wikipedia.org/wiki/Edwin_Hubble



https://en.wikipedia.org/wiki/Subrahmanyan_Chandrasekhar

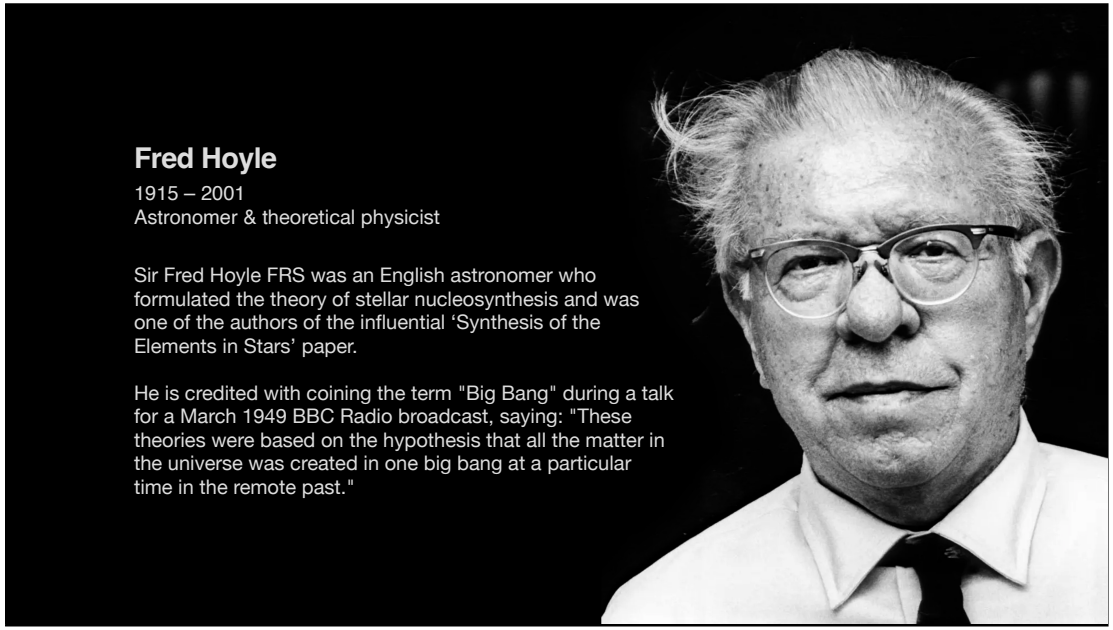


https://en.wikipedia.org/wiki/Cosmic_microwave_background

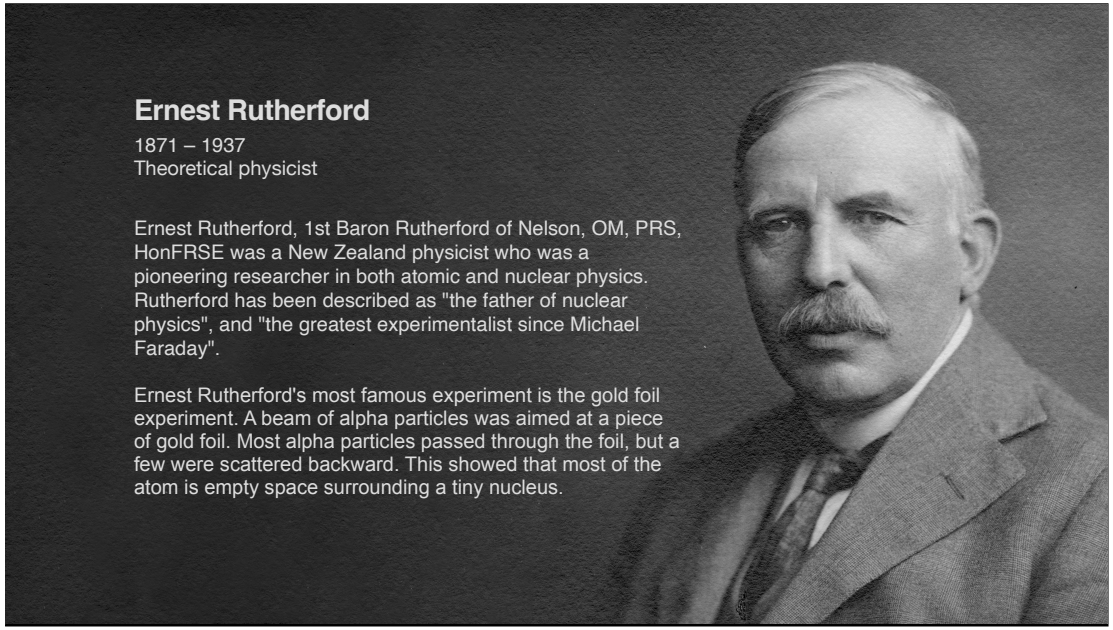
The Cosmic Microwave Background (CMB, CMBR), in Big Bang cosmology, is electromagnetic radiation which is a remnant from an early stage of the universe, also known as "relic radiation"[citation needed]. The CMB is faint cosmic background radiation filling all space. It is an important source of data on the early universe because it is the oldest electromagnetic radiation in the universe, dating to the epoch of recombination. With a traditional optical telescope, the space between stars and galaxies (the background) is completely dark. However, a sufficiently sensitive radio telescope shows a faint background noise, or glow, almost isotropic, that is not associated with any star, galaxy, or other object. This glow is strongest in the microwave region of the radio spectrum. The accidental discovery of the CMB in 1965 by American radio astronomers Arno Penzias and Robert Wilson[1][2] was the culmination of work initiated in the 1940s, and earned the discoverers the 1978 Nobel Prize in Physics.

CMB is landmark evidence of the Big Bang origin of the universe. When the universe was young, before the formation of stars and planets, it was denser, much hotter, and filled with a uniform glow from a white-hot fog of hydrogen plasma. As the universe expanded, both the plasma and the radiation filling it grew cooler. When the universe cooled enough, protons and electrons combined to form neutral hydrogen atoms. Unlike the uncombined protons and electrons, these newly conceived atoms could not scatter the thermal

radiation by Thomson scattering, and so the universe became transparent instead of being an opaque fog.[3] Cosmologists refer to the time period when neutral atoms first formed as the recombination epoch, and the event shortly afterwards when photons started to travel freely through space rather than constantly being scattered by electrons and protons in plasma is referred to as photon decoupling. The photons that existed at the time of photon decoupling have been propagating ever since, though growing fainter and less energetic, since the expansion of space causes their wavelength to increase over time (and wavelength is inversely proportional to energy according to Planck's relation). This is the source of the alternative term relic radiation. The surface of last scattering refers to the set of points in space at the right distance from us so that we are now receiving photons originally emitted from those points at the time of photon decoupling.

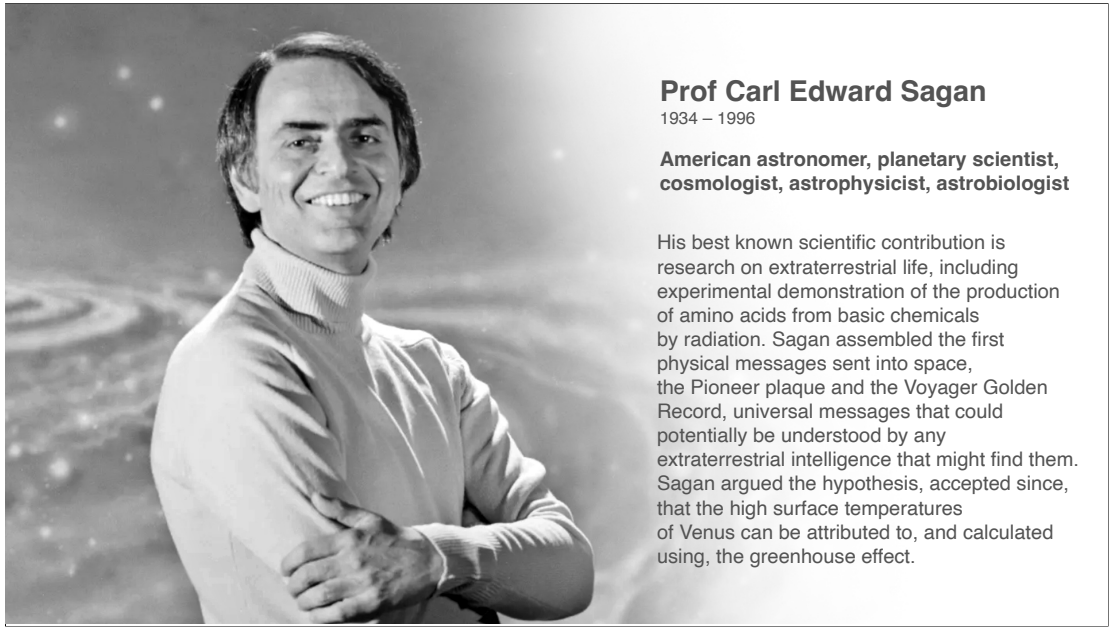


https://en.wikipedia.org/wiki/Fred_Hoyle



https://en.wikipedia.org/wiki/Ernest_Rutherford

https://www.newscientist.com/article/2328087-can-particles-really-be-in-two-places-at-the-same-time/#:~:text=The%20only%20way%20we%20can,and%20one%20through%20the%20right.



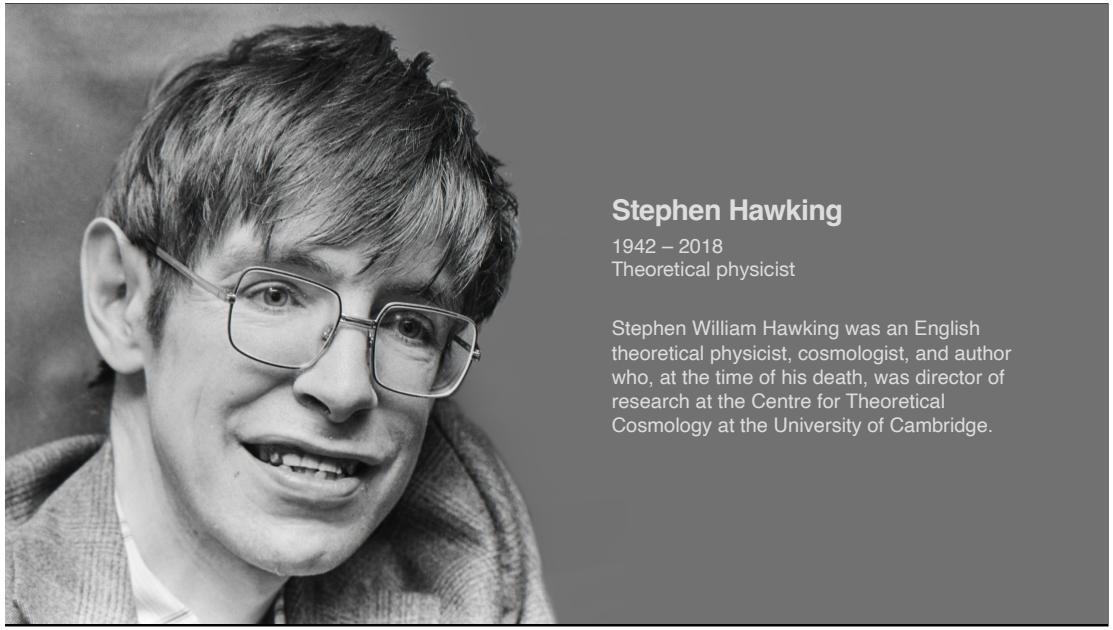
Prof Carl Edward Sagan

1934 – 1996

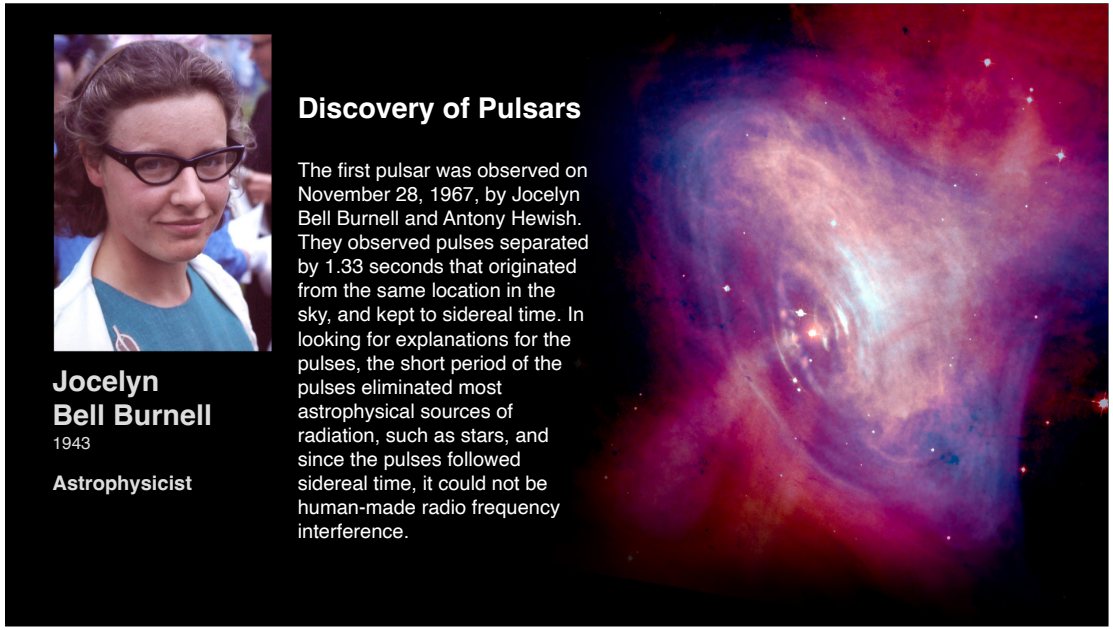
American astronomer, planetary scientist, cosmologist, astrophysicist, astrobiologist

His best known scientific contribution is research on extraterrestrial life, including experimental demonstration of the production of amino acids from basic chemicals by radiation. Sagan assembled the first physical messages sent into space, the Pioneer plaque and the Voyager Golden Record, universal messages that could potentially be understood by any extraterrestrial intelligence that might find them. Sagan argued the hypothesis, accepted since, that the high surface temperatures of Venus can be attributed to, and calculated using, the greenhouse effect.

https://en.wikipedia.org/wiki/Carl_Sagan



https://en.wikipedia.org/wiki/Stephen_Hawking



https://en.wikipedia.org/wiki/Pulsar#:~:text=Cambridge%20University%20Library-,Discovery,and%20kept%20to%20sidereal%20time.

The first pulsar was observed on November 28, 1967, by Jocelyn Bell Burnell and Antony Hewish.[4][5][6] They observed pulses separated by 1.33 seconds that originated from the same location in the sky, and kept to sidereal time. In looking for explanations for the pulses, the short period of the pulses eliminated most astrophysical sources of radiation, such as stars, and since the pulses followed sidereal time, it could not be human-made radio frequency interference.

When observations with another telescope confirmed the emission, it eliminated any sort of instrumental effects. At this point, Bell Burnell said of herself and Hewish that "we did not really believe that we had picked up signals from another civilization, but obviously the idea had crossed our minds and we had no proof that it was an entirely natural radio emission. It is an interesting problem—if one thinks one may have detected life elsewhere in the universe, how does one announce the results responsibly?"[7] Even so, they nicknamed the signal LGM-1, for "little green men" (a playful name for intelligent beings of extraterrestrial origin).

ROYAL
OBSERVATORY
GREENWICH

INTRODUCTION TO ASTRONOMY

Greg Smye-Rumsby - @gregsmyerumsby