@CosmicConundra (on YouTube, Tik Tok, Instagram)

Cosmology Through the Ages:
Geocentrism to Gravitational Waves

Southend History Club

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(Royal Holloway UoL)

The Beecroft Gallery – 08.01.2026

Lecture Overview

- What is Cosmology? (Mythology or Science)
- Why is Cosmology hard?
- A Brief History of Cosmology (Pre 20th Century)
- Modern Cosmology (20th Century and beyond)
- **Why do we care?**

Lecture Live Links (LLL)

Throughout the lecture, I will make a couple of references to previous talks, livestreams, and other online materials.

If you would like to check these out after the talk (or view recordings of previous lectures), please feel free to scan the QR code shown here.

Links and Resources: *Wormholes to Warp Drive* Lecture - 08.07.2025

[1] 'Time Travel 101 - Southend Museum Lecture' - R Clemenson
Previous lecture on special relativity from May 2025 given at the Beecroft Museum, with more details presented, and more historical context.

[2] 'Time Travel from Pythagoras' - R Clemenson
YouTube video from 2020, showing a full derivation of Einstein's time dilation formula using a 'light clock', and no more complicated mathematics than Pythagoras' theorem.

[3] 'Black Holes and Beyond - Southend Museum Lecture' - R Clemenson
Previous lecture with greater detail on general relativity from May 2025. See first 40 minutes for discussion of general relativity.

[4] 'Black Hole Basics - Saturday Spacewalk' - R Clemenson
Livestream from 2021 giving more technical details on general relativity, using some higher mathematics, and applying this to black holes. Don't let the title fool you… This is *far* from basic, and uses quite a lot of University level maths from the beginning!

[5] 'Mercury's Orbital Precession - Saturday Spacewalk' - R Clemenson
Livestream from 2021, deriving the perihelion shift in Mercury's orbit predicted by General Relativity.

Scan the QR code above, or simply click the QR code in the PDF of the lecture slides.

What is Cosmology?

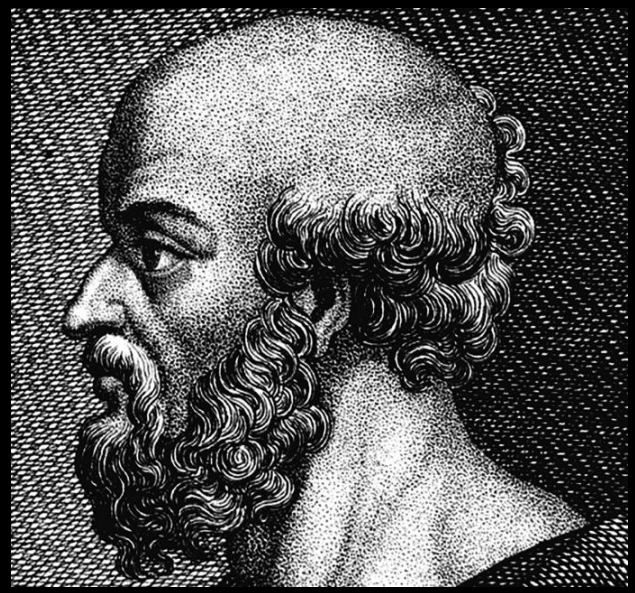
Cosmology as Mythology

Every society throughout human history has had some a *model* of the way the Universe works (a cosmology).

Until around the 16th century, these models were closer to mythology than science.

The boarders between mythology, theology and science did not begin to form until well into the Renaissance.

The Babylonian Map of the World, approx. 9th century BC.



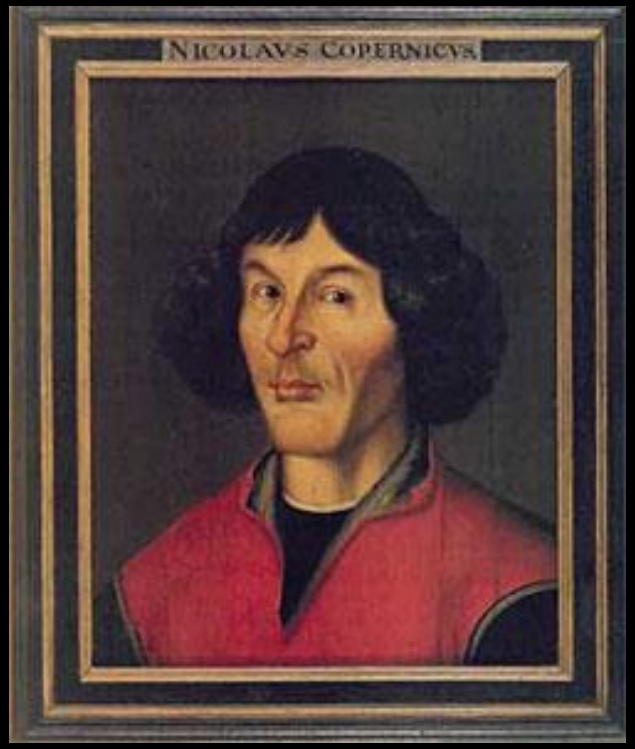
Eratosthenes of Cyrene, approx. 2nd century BC.

Cosmology as Science

From about the 1500's, humans started to apply more formal scientific reasoning to the heavens.

Advances in technology (optical lenses and telescopes) and mathematics (Newton's invention of calculus) formed this early development of cosmology as a science.

Galileo Galilei, 1640



Nicolaus Copernicus, 1580.

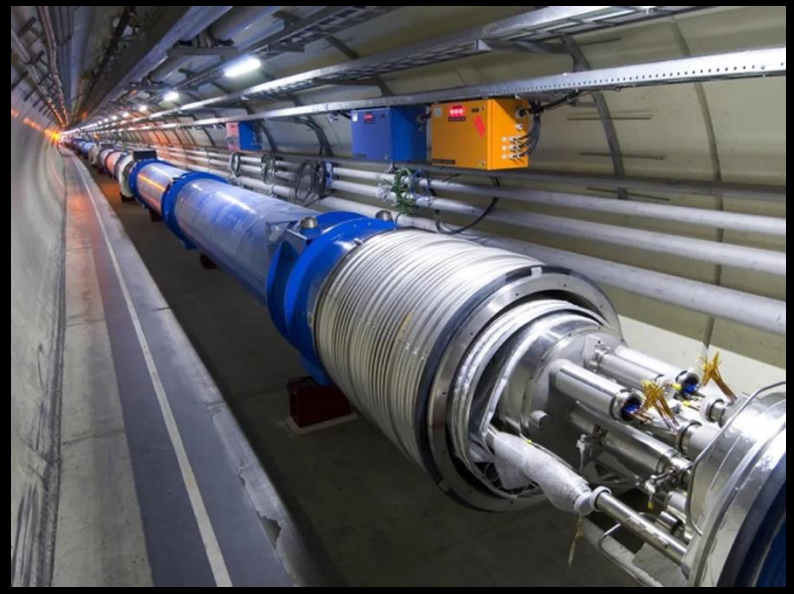
Modern Cosmology

Cosmology is the study of the Universe as a whole.

The main questions of modern cosmology are:

- *What is the origin of the Universe?*
- *What are the larger structures present in the Universe?*
- *What is the matter and energy content of the Universe?*

Modern Cosmology has significant overlaps with Particle Physics.



The Large Hadron Collider at CERN.

The LIGO Facility in Hanford CT.

Why is Cosmology Hard?

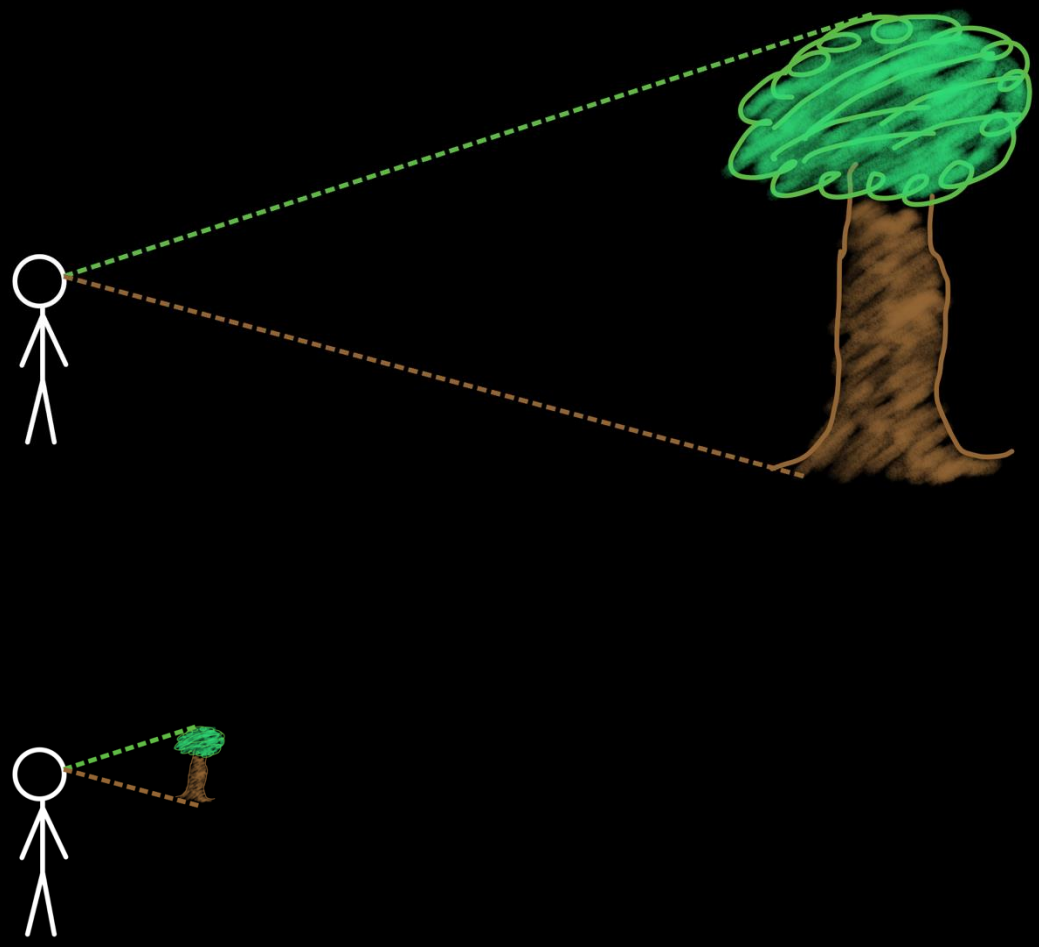
Getting Started…

Biological Handicaps:

- We observe our 3D Universe in 2D.
- Human vision is limited to a narrow band of the EM spectrum.

Philosophical Handicaps:

- Almost every theology claims we / the Earth are central to the existence of the Universe.

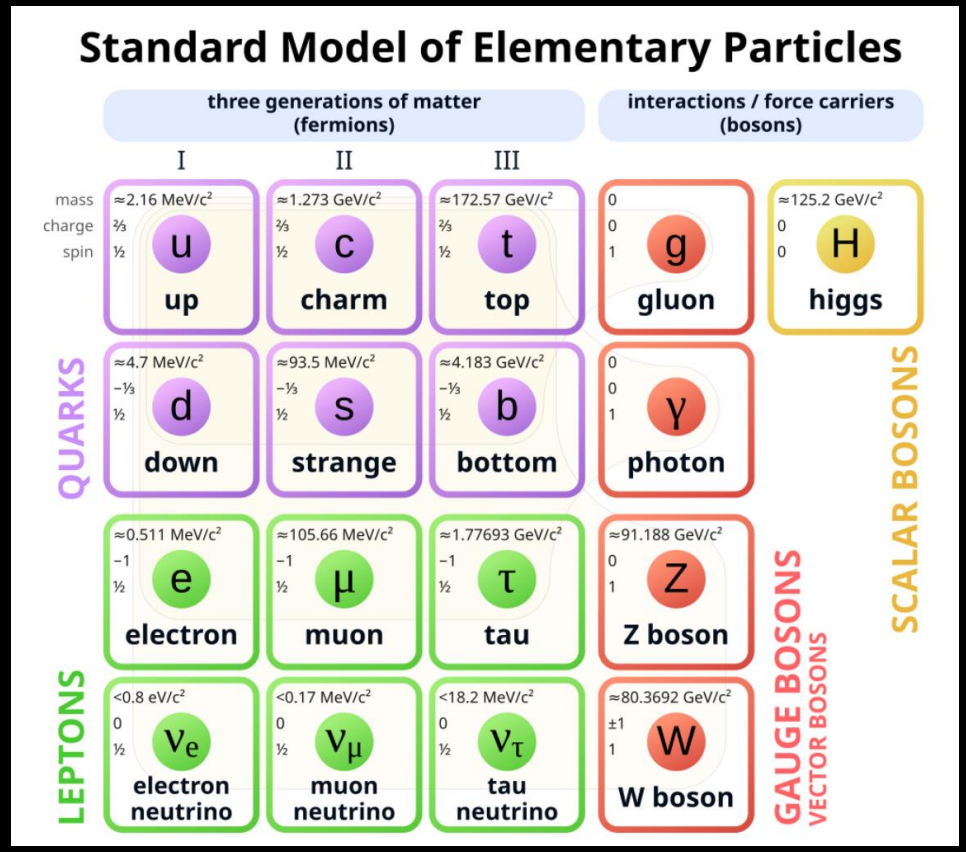


A distant oak tree, and a close-up bonsai tree have the same *apparent size*.

Modern Mysteries

LLL [1]

- Is the Universe Finite, or Infinite?
- Can we reconcile Quantum Mechanics with Gravity to understand the Big Bang Singularity?
- What is the physical nature of Dark Matter?
- What is the physical nature of Dark Energy?



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Modern Mysteries

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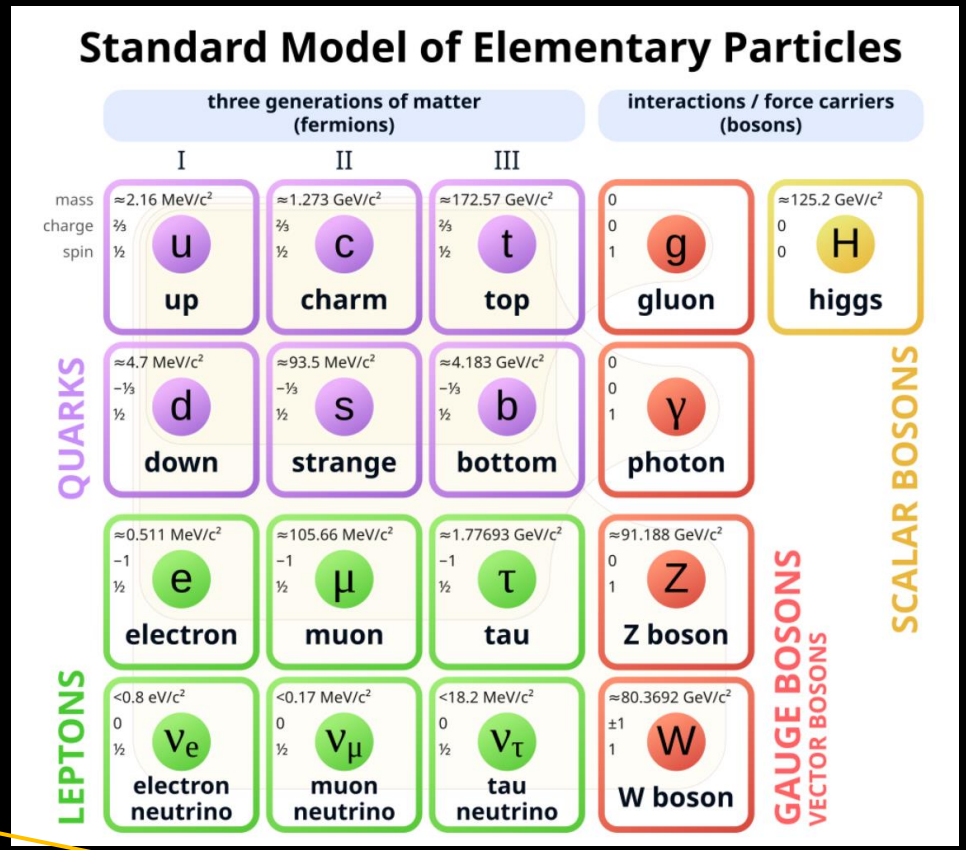

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Hopefully will be solved in my lifetime.

Unlikely to be solved in my lifetime.

A Brief History of Cosmology (Pre 20th Century)

Mesopotamia (3000 BC – 539 BC)

Mesopotamia (roughly, modern day Iraq) was arguably the birthplace of many modern human civilizations.

Home to the Sumerians, Akkadians, and Babylonians from the start of recorded history to the fall of Babylon in 539 BC.

The inhabitants of Mesopotamia had a well developed Mythic-Cosmology (Cosmogony).

The Fall of Babylon - John Martin, 1831.

Mesopotamia (3000 BC – 539 BC)

The *Babylonian Map of the World*, illustrates a *flat circular Earth* surrounded by a *Cosmic Ocean*, and enclosed by a solid Firmament that holds the stars

The idea of a Cosmic Ocean, birthing the Earth and skies is quite common in Ancient Cosmology.

(Perhaps this isn't so surprising!..)

The *Cosmic Ocean*, surrounding the Earth.

A Flat Circular Earth, with Mountain, Swamp and City regions described

The Babylonian Map of the World, approx. 9th century BC.

Greece
(600 BC – 100 BC)

The Ancient Greeks passed down their philosophy, literature and (proto-) science to their intellectual descendants throughout the western world.

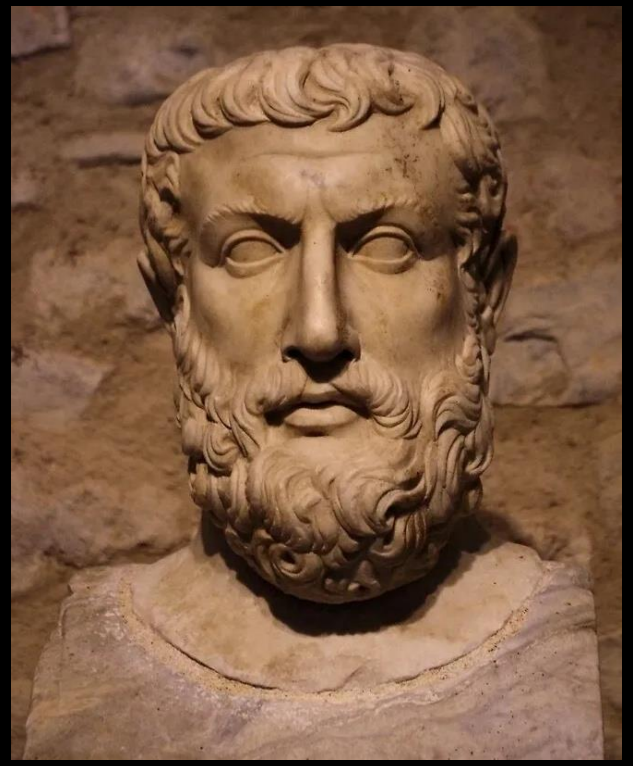
Greek Cosmology saw many advances, blending the mythology of the Ancient Near East with the fledgling science of Astronomy.

The Acropolis at Athens – Leo von Klenze, 1846.

Greece (600 BC – 100 BC)

Parmenides is often credited as the first Greek philosopher to suggest a spherical Earth.

Some dispute this… And besides, it was based on abstract reasoning, not astronomical observation.



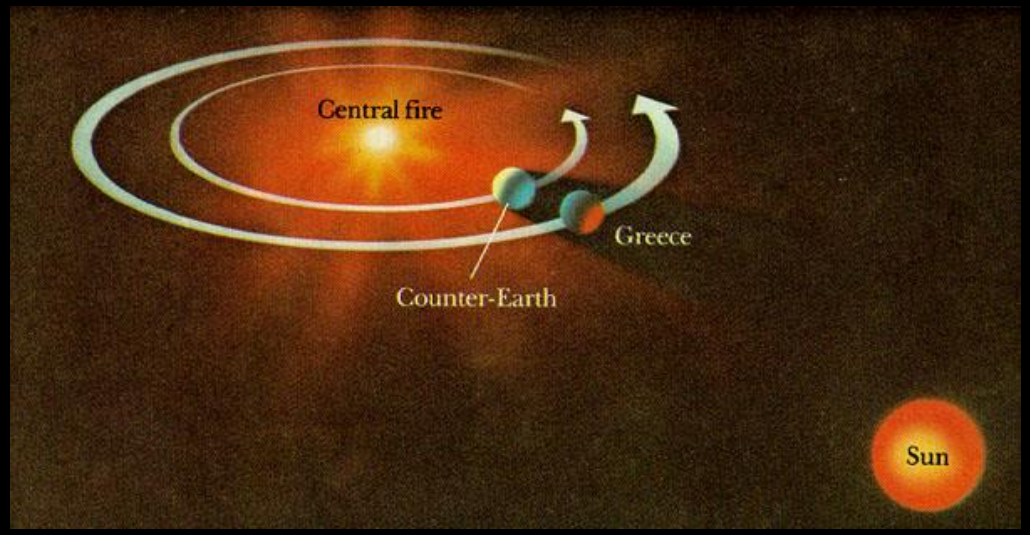
Parmenides of Elea, 5th Century BC.

The Greek's give a name for the 'wandering lights' known to the Babylonians:

Πλανήτης (planets) – 'Wanderers'

Despite this new nomenclature, there was no physical distinction made between stars and planets.

Philolaus (a Pythagorean philosopher) believe the motion of the planets were fuelled by a Central Fire; about which the Earth, Sun, Moon and other planets revolved.



Philolaus' 'Central Fire' and 'Counter-Earth model.

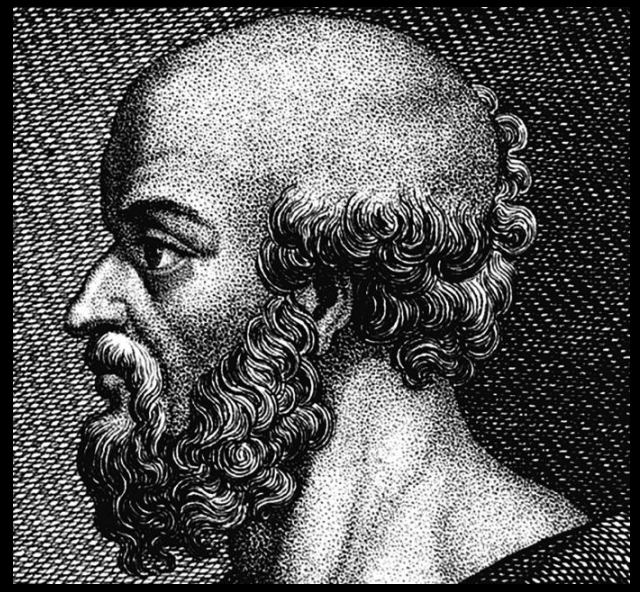
Greece
(600 BC – 100 BC)

Due to their advancements in Geometry, the Greeks were able to compute a number of astronomical lengths.

Eratosthenes calculated the circumference of the Earth with very high accuracy for the time.

Hipparchus calculated the distance between the Earth and the moon, also to very high accuracy for the time.

Hipparchus of Rhodes, approx. 2nd century BC.



Eratosthenes of Cyrene, approx. 2nd century BC.

Copernican Heliocentrism (Published 1543)

Copernicus replaces Ptolemy's geocentric model, with his heliocentric model.

This posits circular orbits of the planets (including Earth) around the sun, moving with constant velocity.

Copernicus' model still involved unphysical 'epicycles' to account for irregular motion of the planets.

Still includes a fixed and distant 'firmament' with distant stars attached.

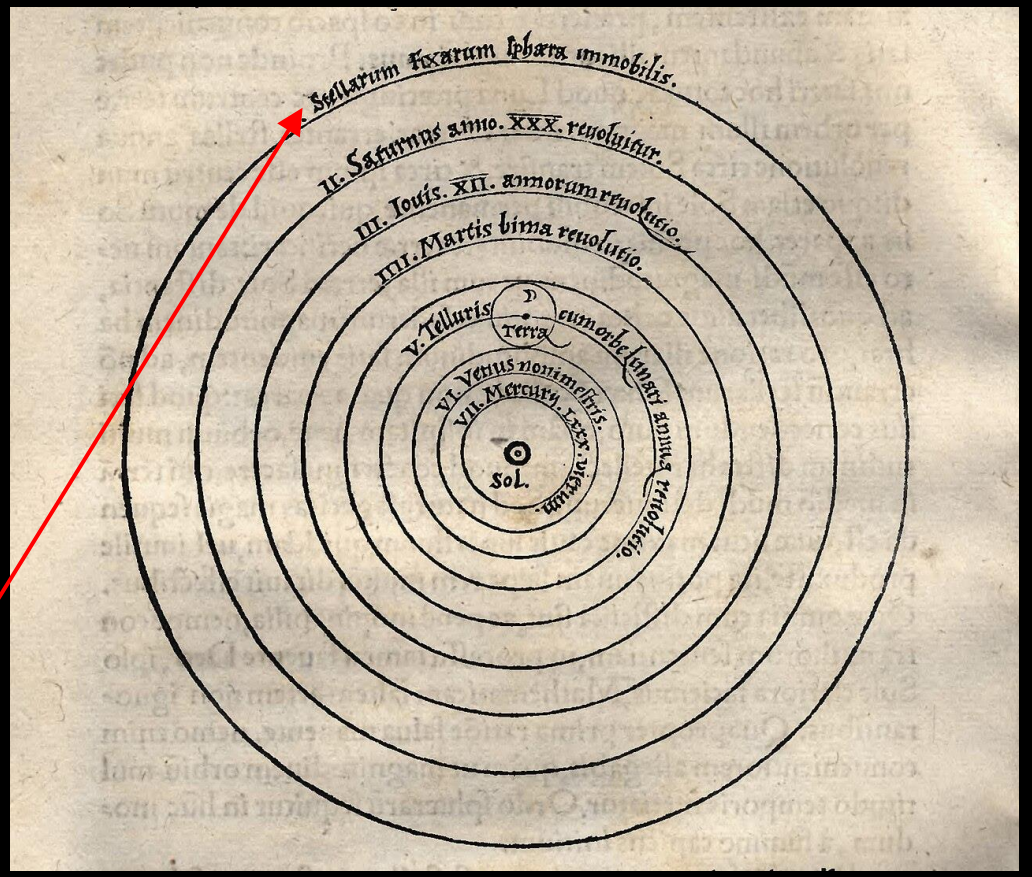


Figure from De Revolutionibus Orbium Coelestium.

Nicolaus Copernicus, 1580.

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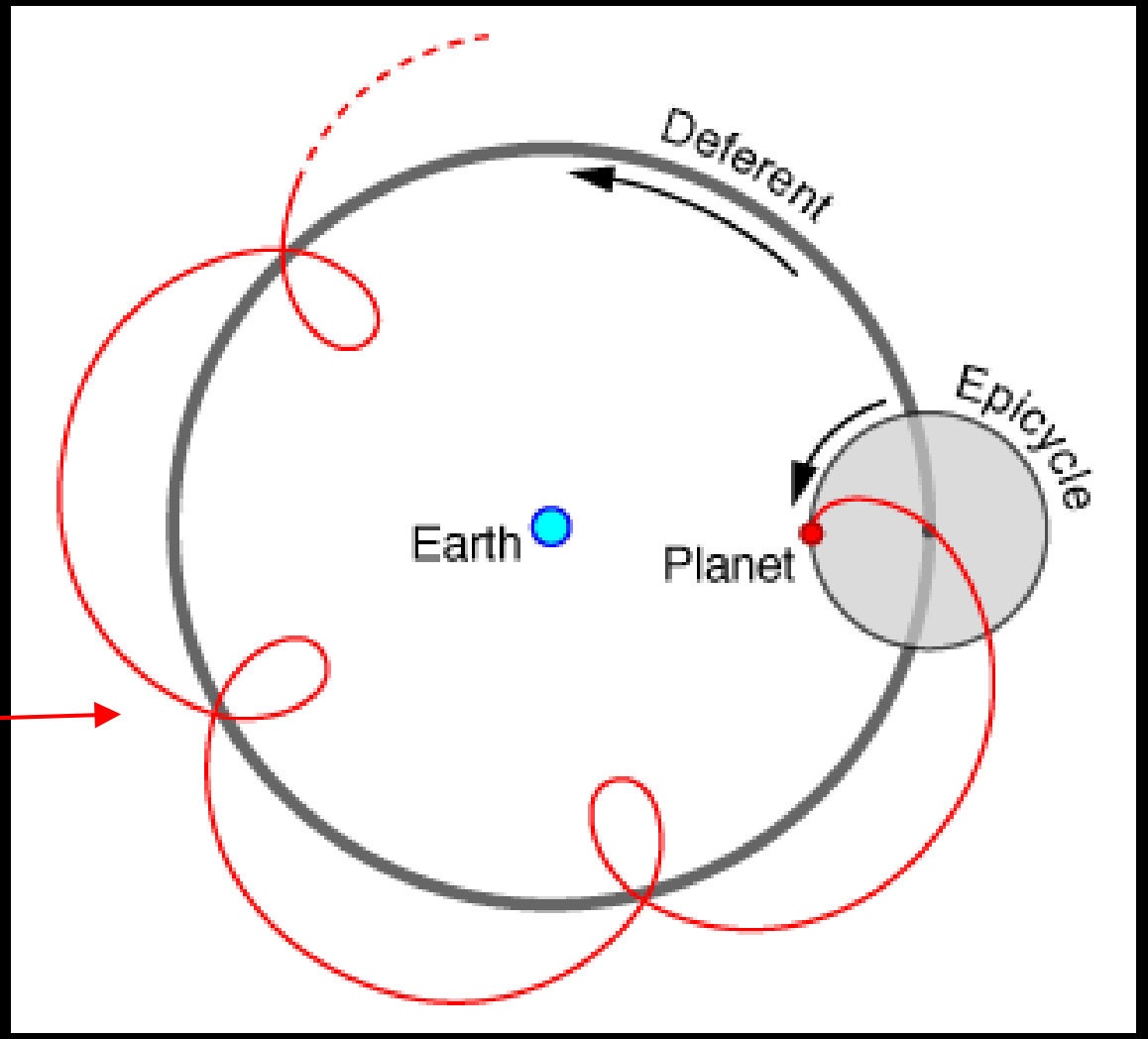
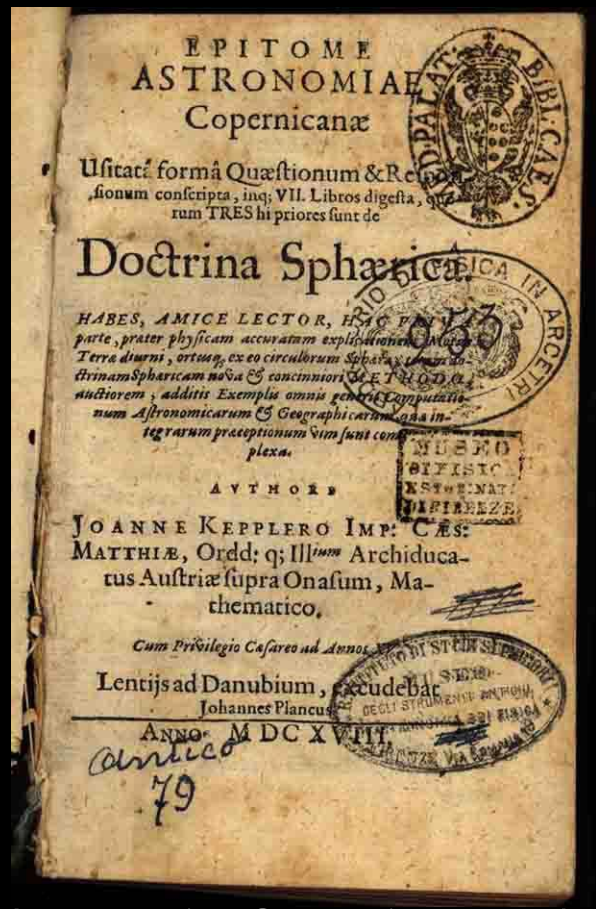


Keplerian Heliocentrism (Published 1609, 1619, 1621)

Kepler publishes three works in the first quarter of the 17th century.

He outlines his three laws of planetary motion (updating Copernicus' model and removing the need for epicycles).



EPITOME
ASTRONOMIAE
Copernicanæ

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AUTHORE

JOANNE KEPPLERO IMP: CÆS:
MATTHIÆ, Ordd: q; Illſtrium Archiduca-
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thematico.

Cum Privilegio Cæſareo ad Annos

Lentijs ad Danubium, excudebat
Johannes Plancus.

ANNO M DC XVIII.

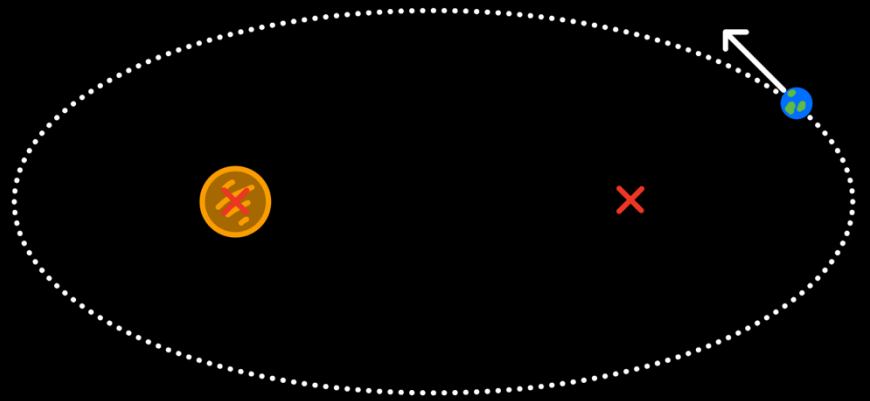
Epitome Astronomiae Copernicanae, where Kepler first published his three laws together.

Johannes Kepler, 1610.

Kepler's Laws of Planetary Motion

Kepler's First Law

Planets move along elliptical paths, with the sun centered at one focus.

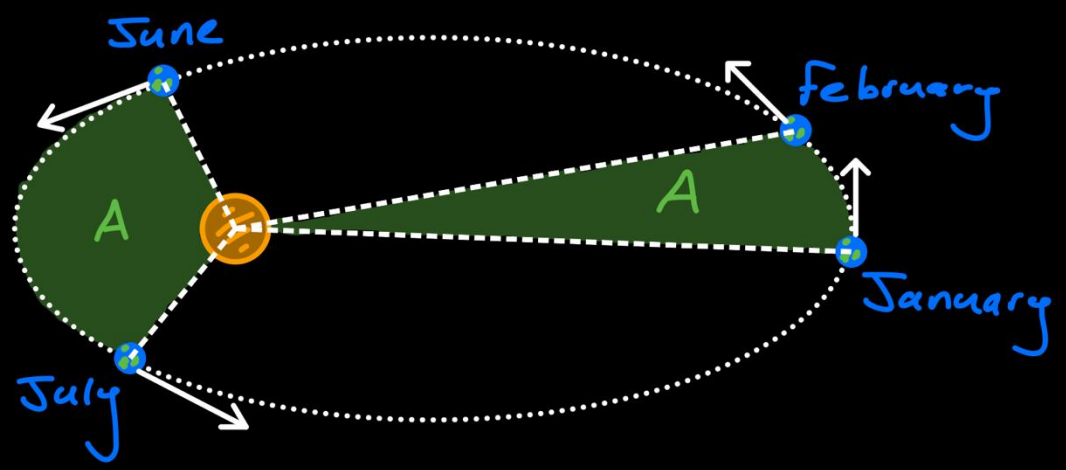


An ellipse is a kind of squashed circle, with geometric properties that have been studied by mathematicians since the 4th century BC.

Kepler's Laws of Planetary Motion

Kepler's Second Law

The area *swept out* by a planet in orbit is unchanged, given a fixed duration.

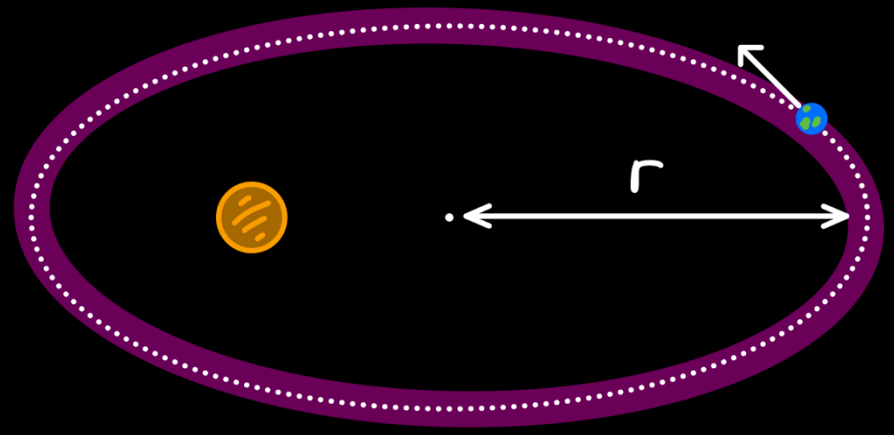


The origin of this law, is the conservation of angular momentum. As a planet moves closer to its star, it speeds up.

Kepler's Laws of Planetary Motion

Kepler's Third Law

The square of the orbital period is directly proportional to the cube of the orbital radius cubed.



$$T^2 \propto r^3$$

This law was the key for Newton to work out his equation of gravity.

Technically an ellipse doesn't have a radius... The length shown is in fact called the *semi-major axis* of the ellipse.

Halley's Proper Motion (Published 1718)

Think for a moment about how remarkable this is.

Halley notices that the the current positions of a handful of distant stars have changed since the time of Hipparchus.

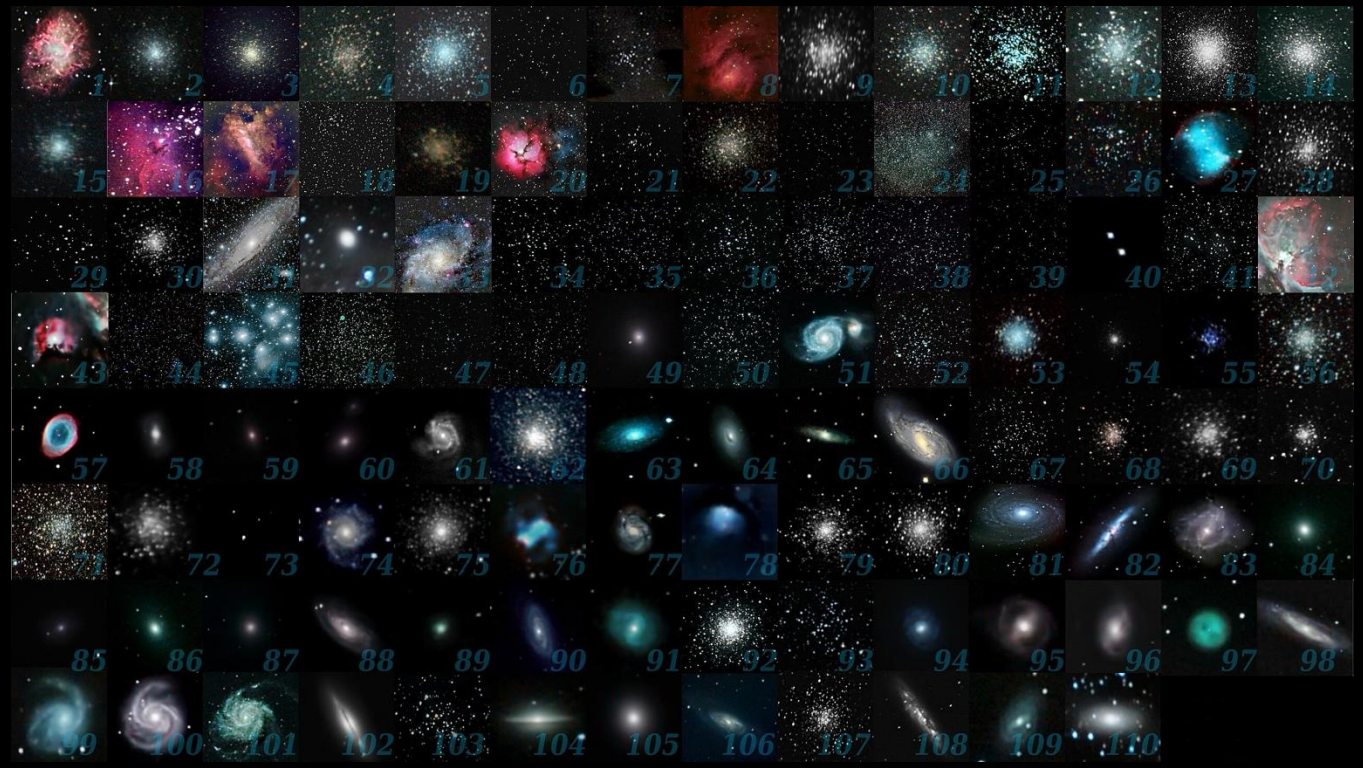
In particular… He notices that most stars have not shifted their positions to any measurable degree, apart from a few that have moved more substantially. Namely, Sirius, Aldebaran, and Arcturus.

This means there is no firmament.. The stars are free to move!

Edmond Halley, 1690.

The Messier Catalogue (Published 1781)

Messier observes, catalogues and publishes a list of 110 ‘non-comet’ objects. These objects will be determined later to include: galaxies, nebulae, and star clusters.



All 110 Messier objects.

Charles Messier, 1770

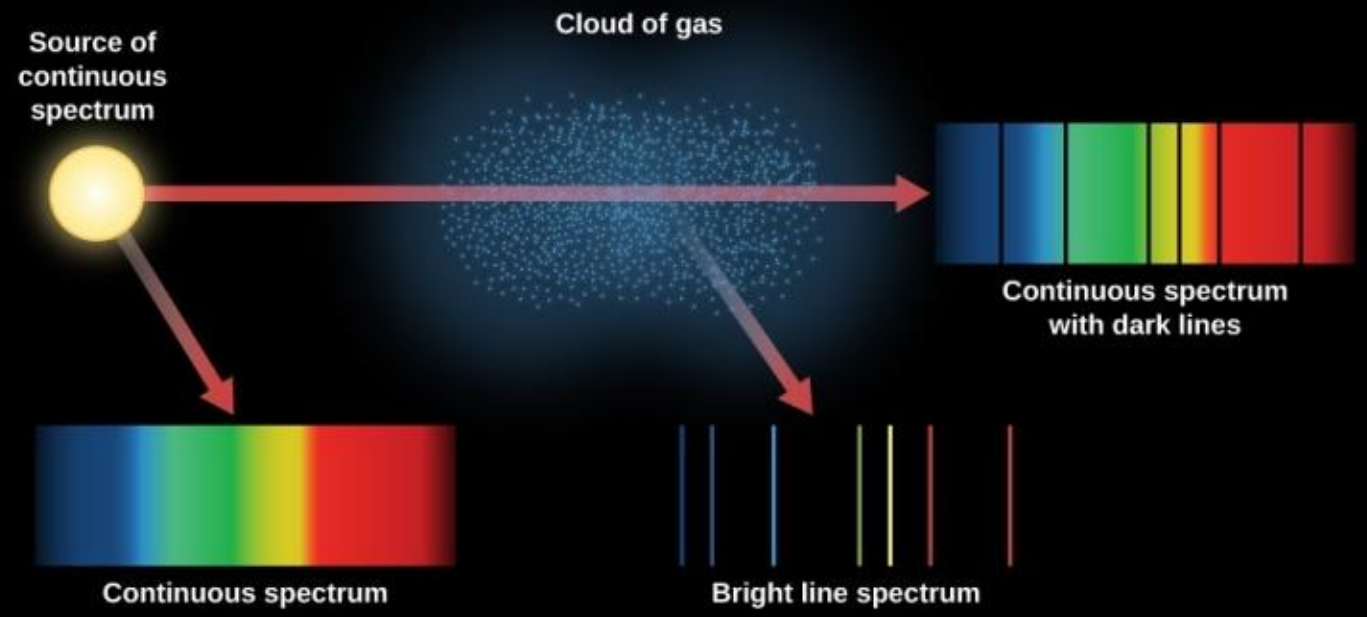
The Sun is a Star (1814 - 1868)

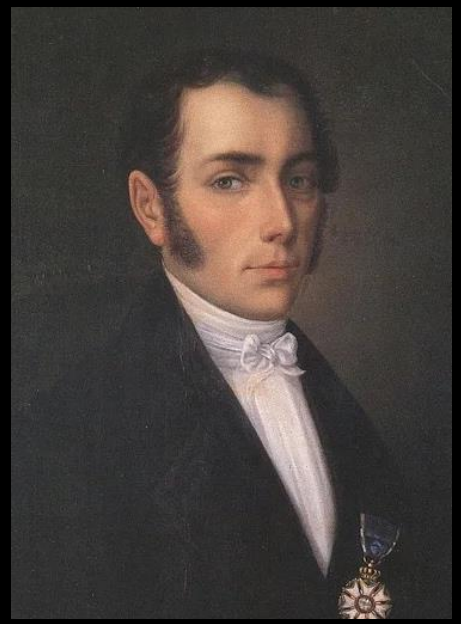
Fraunhofer finds *spectral lines* in sunlight (1814)

Kirchoff and Bunsen identify *spectral lines* with the chemical elements (1860).

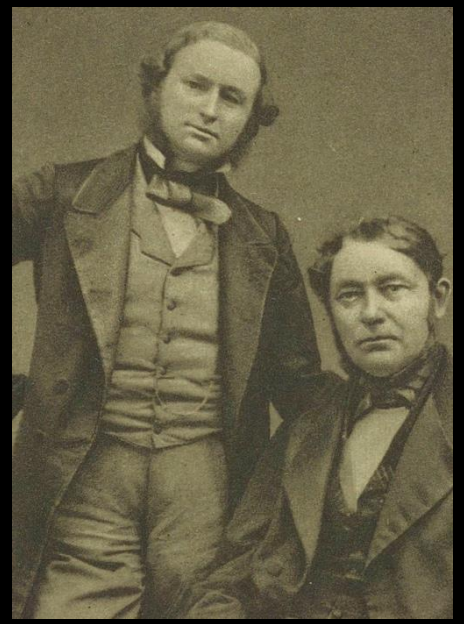
Secchi shows that the sun and the stars emit the same *spectral lines* (1868).

So, the Sun is a Star.





Joseph von Fraunhofer, approx. 1810



Gustav Kirchoff and Robert Bunsen, 1860

Father Angelo Secchi, approx. 1870

‘Nebulae’ (Published 1864 and 1865)

Prior to Huggins and Huggins (a married duo), Messier objects were collectively referred to as *nebulae*.

By studying the light coming from different ‘nebulae’, the Huggins and Huggins established that not all of Messier’s objects are the same.

Specifically, they showed than the Orion Nebula (M42) and the Andromeda Nebula (M31) were different types of objects.

Margaret Huggins, approx. 1900

William Huggins, 1905.

Modern Cosmology
(20th Century – Present)

1900 – State of the Field

Known Knowns:

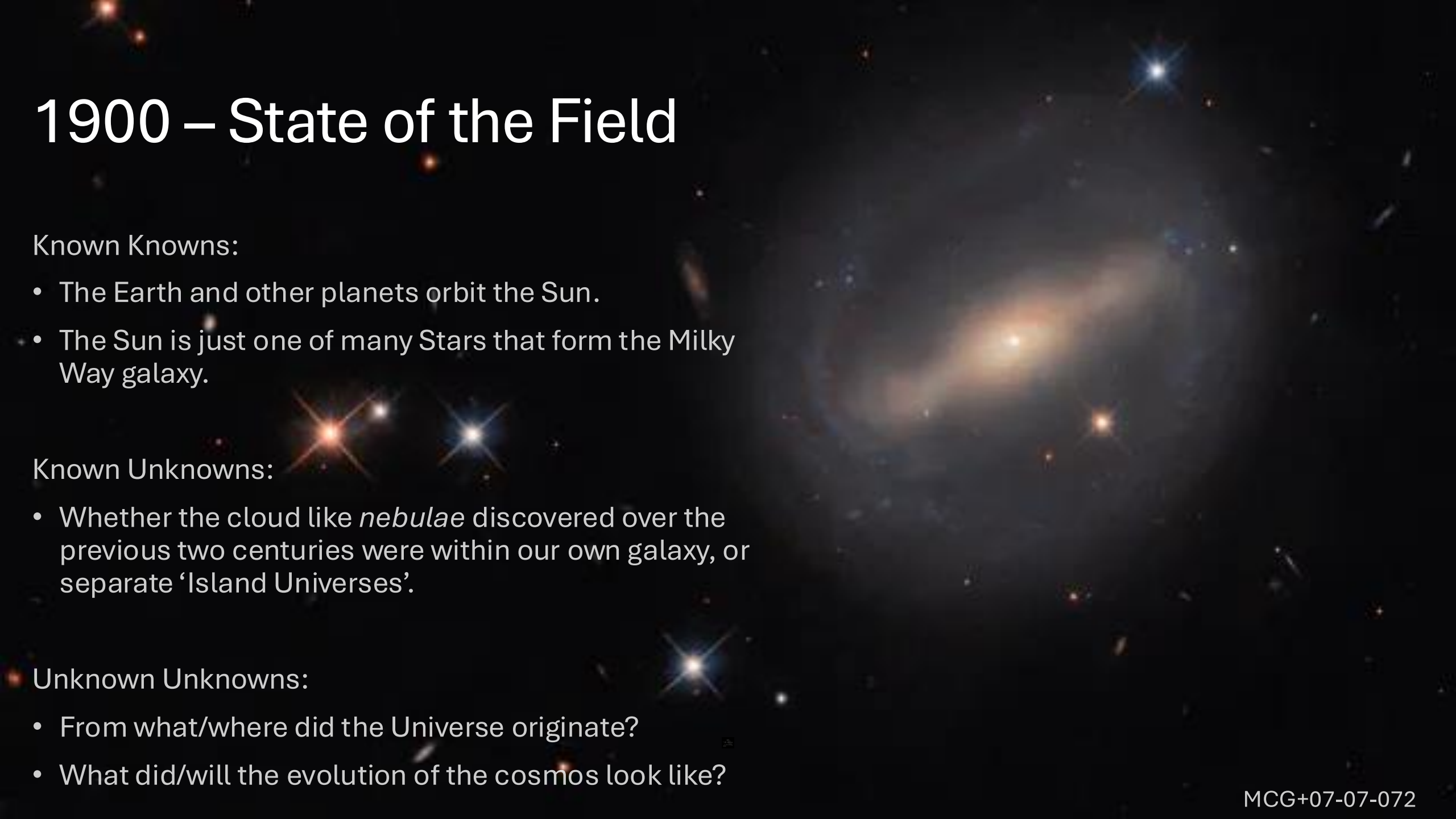
- The Earth and other planets orbit the Sun.
- The Sun is just one of many Stars that form the Milky Way galaxy.

Known Unknowns:

- Whether the cloud like *nebulae* discovered over the previous two centuries were within our own galaxy, or separate ‘Island Universes’.

Unknown Unknowns:

- From what/where did the Universe originate?
- What did/will the evolution of the cosmos look like?



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A Golden Age for Physics

The 20th century provided fertile opportunity for advancing our understanding of the cosmos.

In the first third of the 20th century:

- Einstein's theory of gravity (general relativity).
- The development of quantum mechanics.
- Advances in ground based optical telescopes.
- The birth of radio-astronomy

The fifth Solvay Conference, 1927.

External Galaxies (1917, 1925)

In 1917, the Hooker Telescope (a 100-inch reflecting telescope) was completed.

Advances in photographic technology allowed longer exposure (and higher resolution) images to be made.

In 1925, Hubble publishes his observations – showing individual stars in the Andromeda Nebula, prompting its renaming:

The Andromeda Galaxy.

Mount Wilson Observatory in the San Gabriel mountains, North of Los Angeles.

One of Hubble's original photographic plates of Andromeda.

Edwin Hubble, approx. 1930.

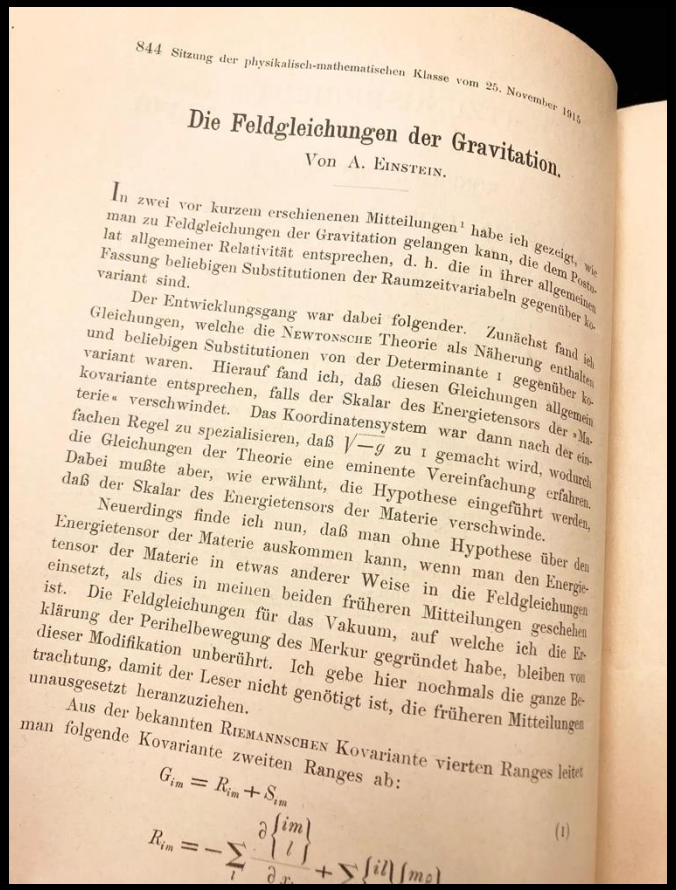
General Relativity (1915)

LLL [2]

In November 1915, Albert Einstein publishes four papers, on four successive Thursdays.

The fourth of these papers, *The Field Equations of Gravitation*, sets out Einstein's new mathematical description of gravity.

The details of Einstein's theory are highly complex, but we will discuss some of the core ideas.



844 Sitzung der physikalisch-mathematischen Klasse vom 25. November 1915

Die Feldgleichungen der Gravitation.

Von A. Einstein.

In zwei vor kurzem erschienenen Mitteilungen[1] habe ich gezeigt, wie man zu Feldgleichungen der Gravitation gelangen kann, die dem Postulat allgemeiner Relativität entsprechen, d. h. die in ihrer allgemeinen Fassung beliebigen Substitutionen der Raumzeitvariabeln gegenüber kovariant sind.

Der Entwicklungsgang war dabei folgender. Zunächst fand ich Gleichungen, welche die Newtonsche Theorie als Näherung enthalten und beliebigen Substitutionen von der Determinante 1 gegenüber kovariant waren. Hierauf fand ich, daß diesen Gleichungen allgemein kovariante entsprechen, falls der Skalar des Energietensors der »Materie« verschwindet. Das Koordinatensystem war dann nach der einfachen Regel zu spezialisieren, daß $\sqrt{-g}$ zu 1 gemacht wird, wodurch die Gleichungen der Theorie eine eminente Vereinfachung erfahren. Dabei mußte aber, wie erwähnt, die Hypothese eingeführt werden, daß der Skalar des Energietensors der Materie verschwinde.

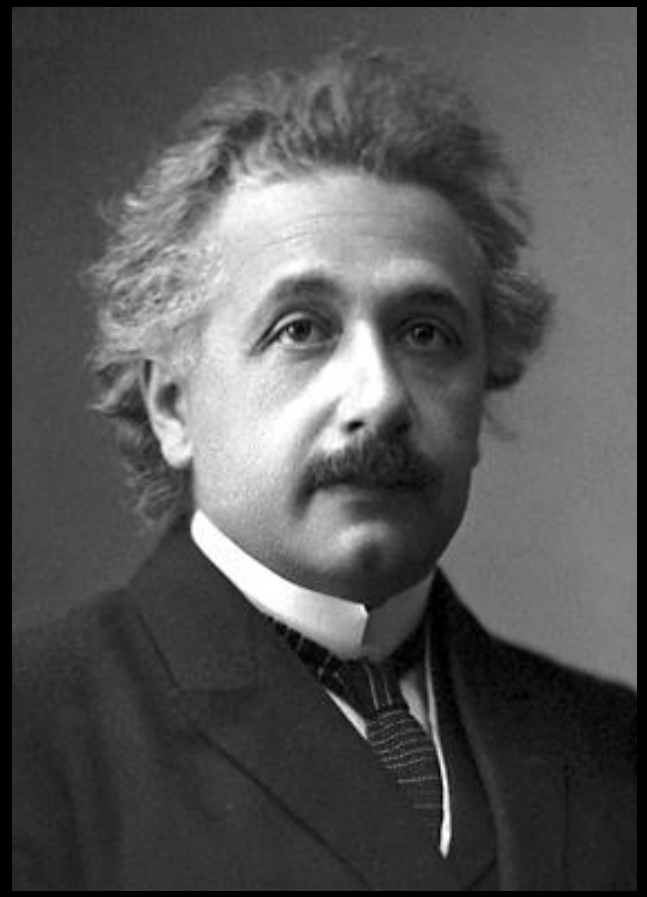
Neuerdings finde ich nun, daß man ohne Hypothese über den Energietensor der Materie auskommen kann, wenn man den Energietensor der Materie in etwas anderer Weise in die Feldgleichungen einsetzt, als dies in meinen beiden früheren Mitteilungen geschehen ist. Die Feldgleichungen für das Vakuum, auf welche ich die Erklärung der Perihelbewegung des Merkur gegründet habe, bleiben von dieser Modifikation unberührt. Ich gebe hier nochmals die ganze Betrachtung, damit der Leser nicht genötigt ist, die früheren Mitteilungen unausgesetzt heranzuziehen.

Aus der bekannten Riemannschen Kovariante vierten Ranges leitet man folgende Kovariante zweiten Ranges ab:

$$G_{im} = R_{im} + S_{im}$$

$$R_{im} = -\sum_{l} \frac{\partial \left\{ \begin{matrix} im \\ l \end{matrix} \right\}}{\partial x_{}} + \sum \left\{ il \right\} \left\{ m_{} \right\} \qquad (1)$$

The Field Equations of Gravitation, published Nov 25th 1915.

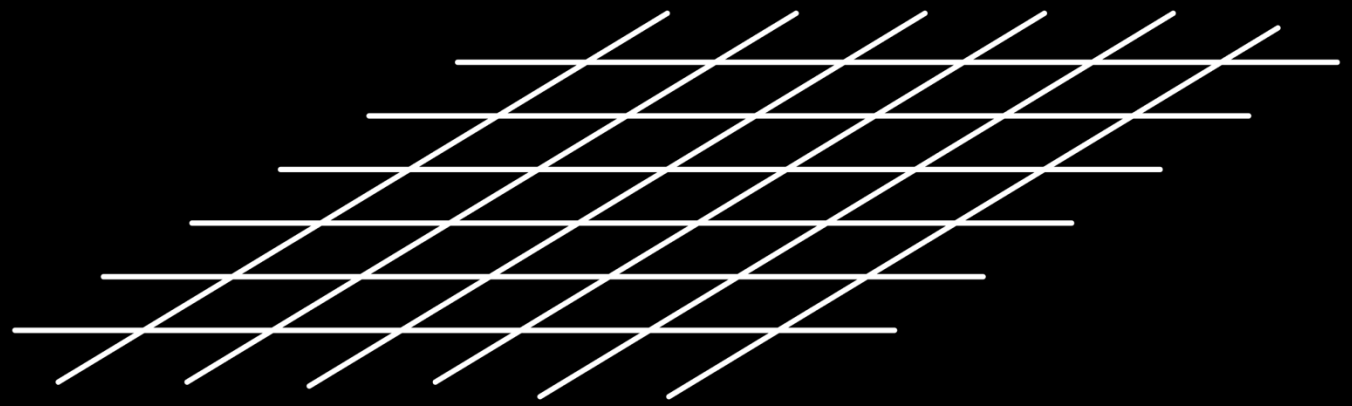


Albert Einstein, 1921.

General Relativity (1915)

Einstein's theory of gravity is radically different to Newton's 17th century theory... Einstein reformulates gravity as a *geometric phenomena*.

Einstein's earlier work on the theory of special relativity (1905) puts space and time into a single united framework, *four-dimensional space time*.



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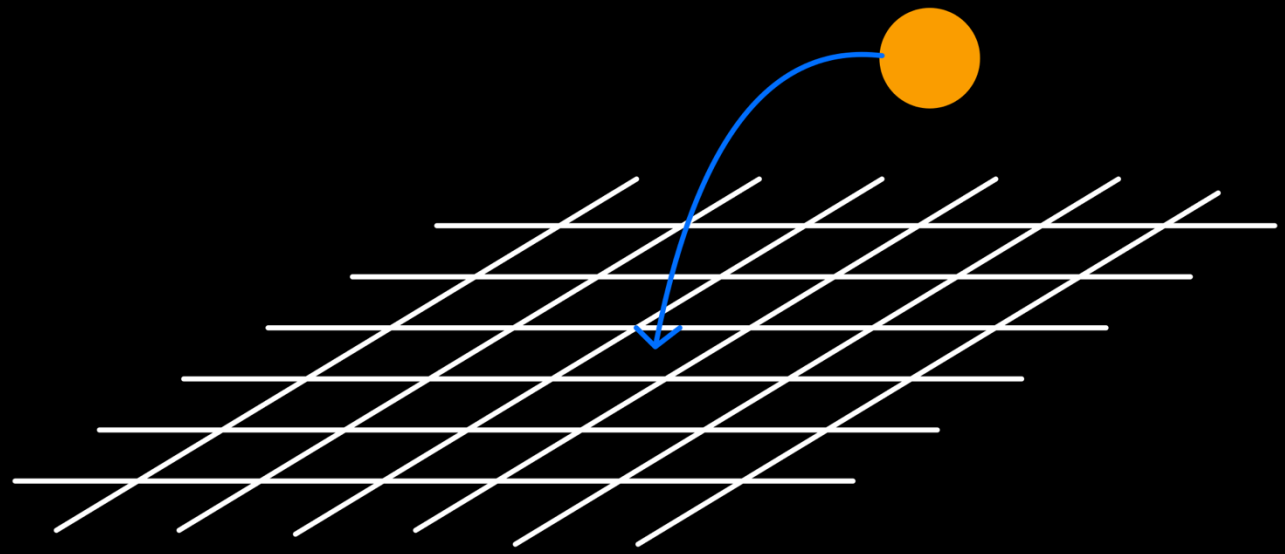
Space and time are more than just the stage on which physics happens, they are players.

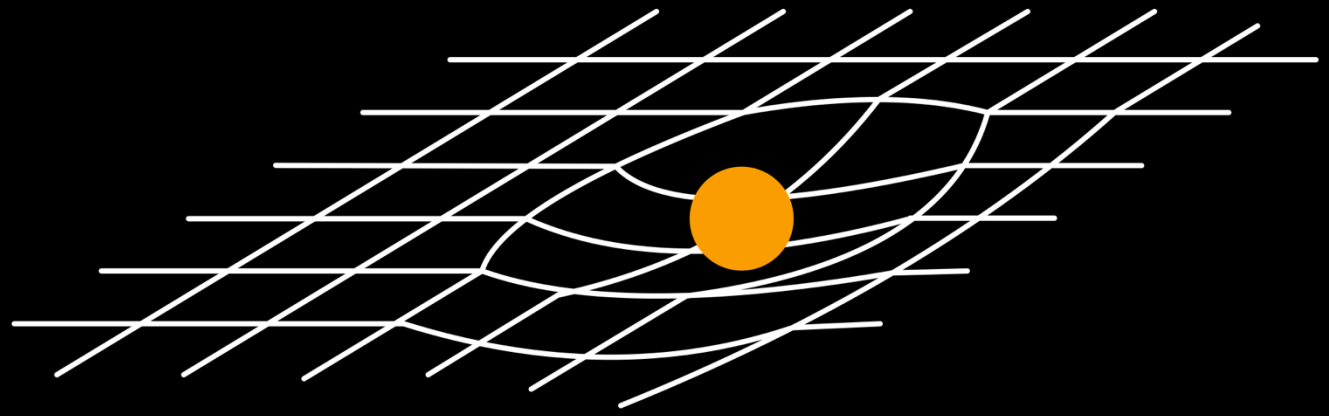


Let's add a piece of matter into this flat region of space.

General Relativity (1915)

The presence of matter, causes space-time to curves.

The curvature of space-time cases matter to experience the illusion of a gravitational force.



'Spacetime tells matter how to move; matter tells spacetime how to curve.' – John Wheeler

$$G_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}$$

Space-time Curvature

Speed of light

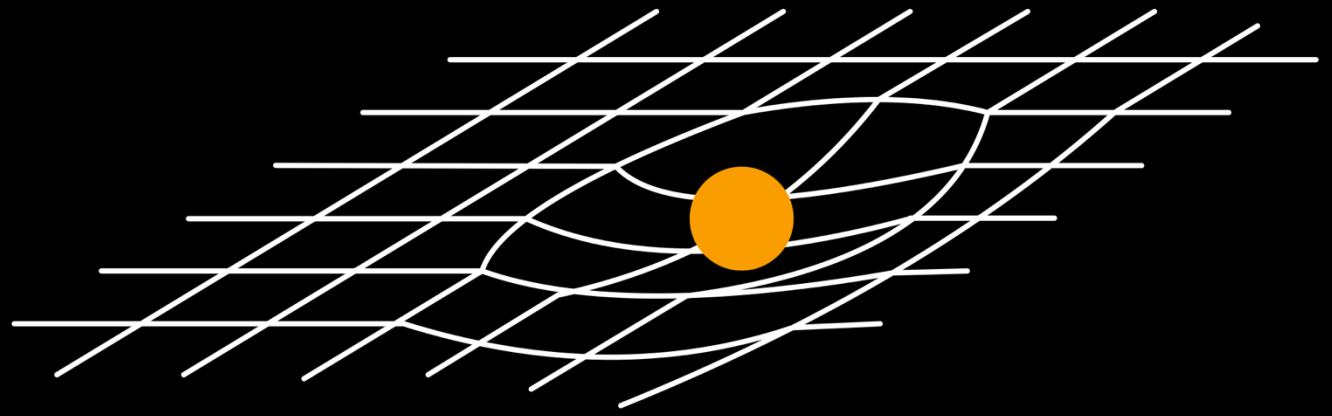
Matter

Space-time is more than just the stage on which physics happens, they are players too.

General Relativity (1915)

LLL [3]

More theory on General Relativity:



$$G_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}$$

Space-time Curvature

Speed of light

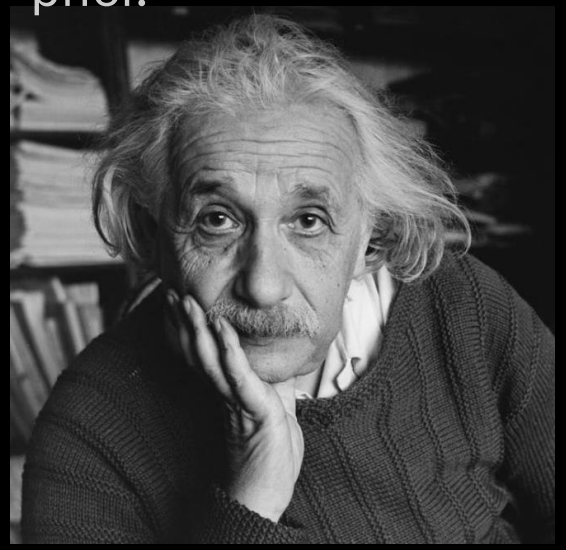
Matter

Not for the faint of heart!...

The Big Bang Theory (no.. not that one...)

In 1922, Alexander Friedmann published his equations for calculating the changing size of the Universe.

His equations (now called 'The Friedmann Equations') spring from Einstein's theory of gravity (general relativity), published seven years prior.



Albert Einstein circa 1950

Alexander Friedmann circa 1920

Pi: 1900 BC Ancient Babylon

Newton's gravitational constant: 17th century England

The speed of Light: 17th century Denmark

$$H^2 = \frac{8\pi G}{3}\rho - \frac{kc^2}{a^2} + \frac{\Lambda c^2}{3}$$

Density of matter in the Universe

Einstein's "Cosmological constant"

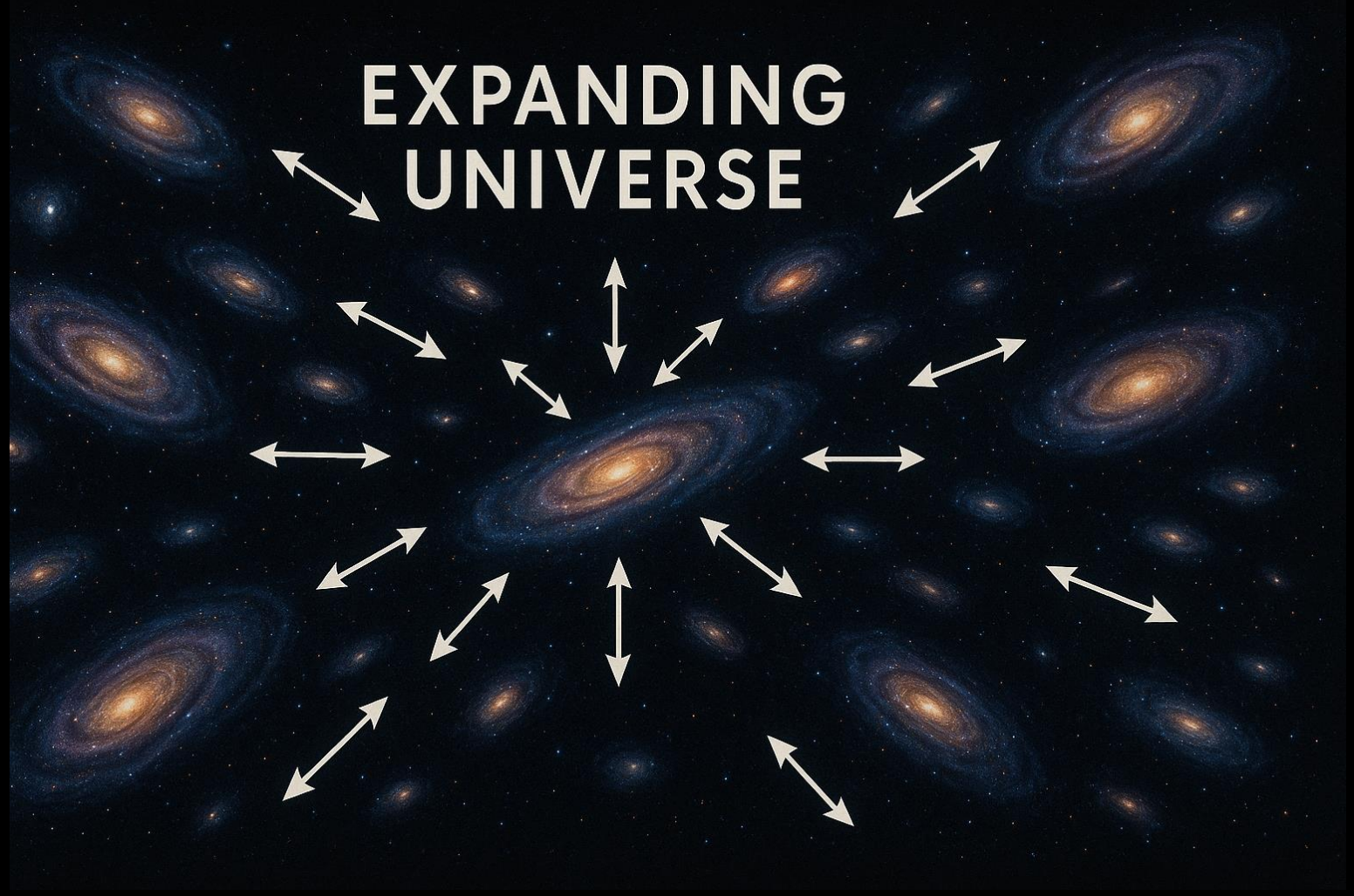
We will return to the Cosmological Constant later...

The Big Bang Theory (no.. not that one...)

Friedmann's equation shows us that it is possible that the Universe could change in size.

This was puzzling, as the prevailing scientific theory in the 1920's was the so called 'Steady State Theory'.

Fred Hoyle circa 1955



In an expanding Universe, every Galaxy moves away from every other galaxy. There is no common center to the expansion.

So... Is the Universe expanding or not?

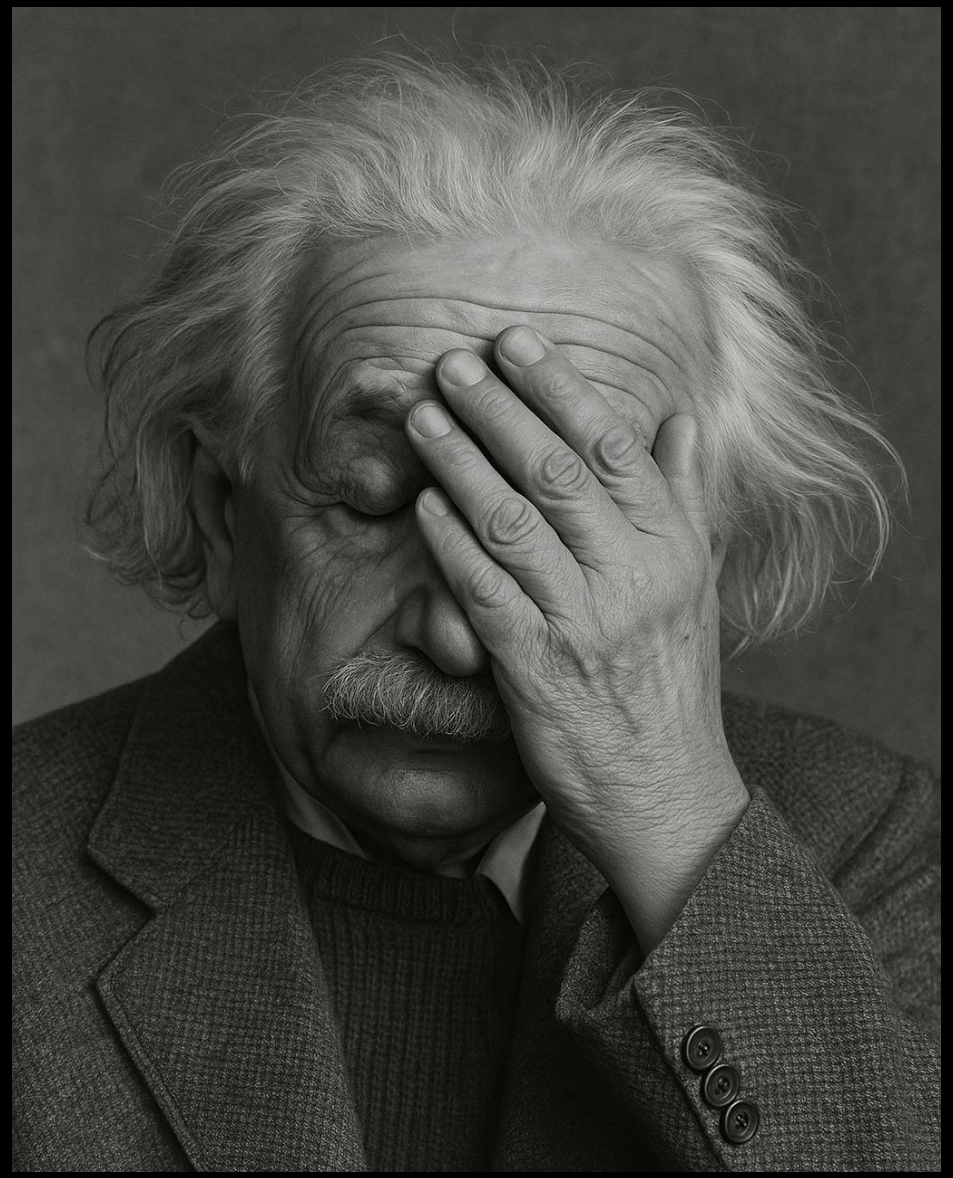
The Big Bang Theory (no.. not that one...)

The belief that the Universe is static in size first led Einstein to add a 'Cosmological Constant' into his equations of gravity.

This term acts to increase the density of energy in the Universe, to pull the galaxies back together and stop them from expanding away from one another.

He would later refer to his invention of this constant as his "biggest blunder".

But was Einstein completely wrong?.... We will see later.



Note: This is an AI generated image.

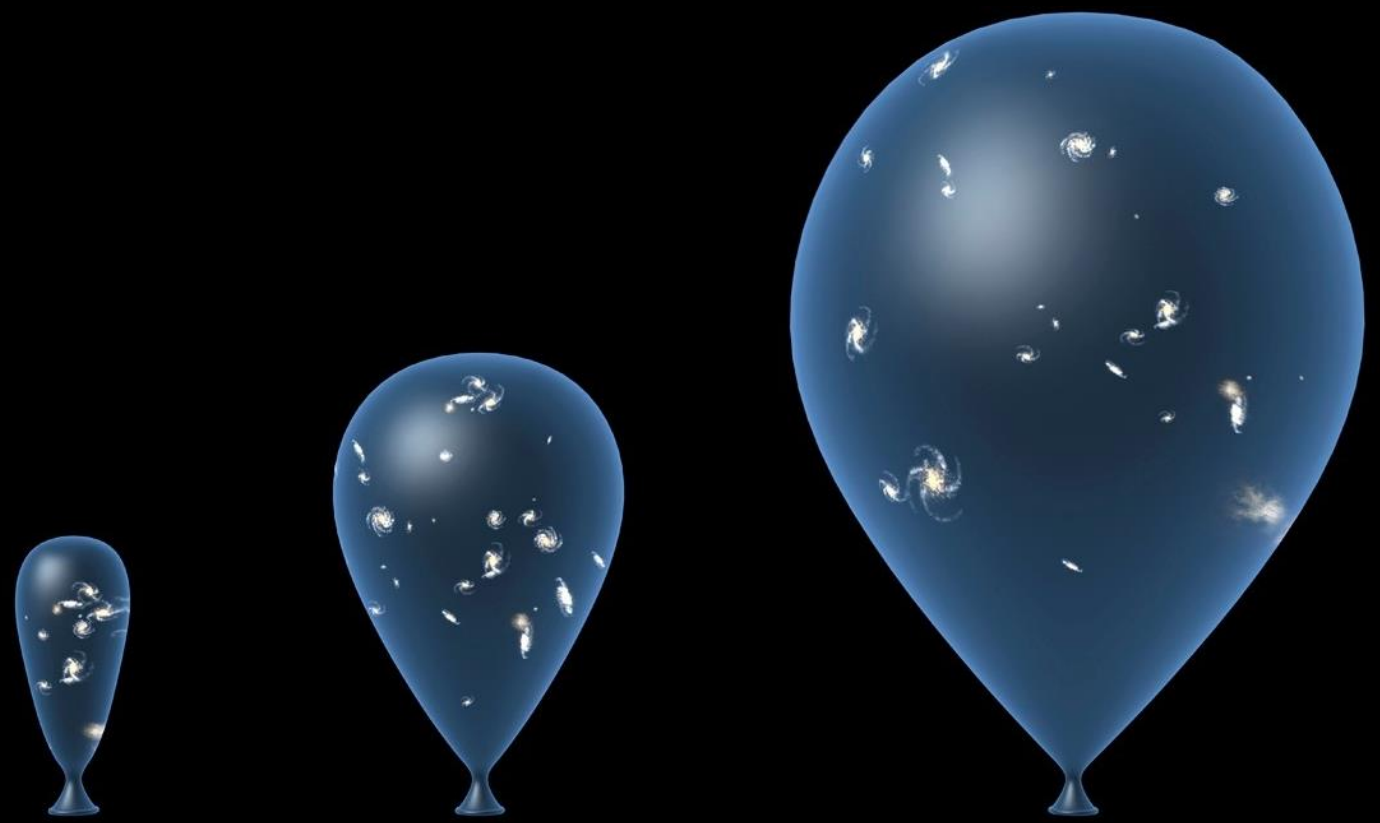
The Big Bang Theory (no.. not that one...)

In 1929, Edwin Hubble publishes his observations that distant galaxies are moving away from us, with the more distant galaxies moving away at higher speeds.

In 1931, Georges Lemaître proposes that the Universe might have begun from a single point that he called ‘the primeval atom’.

Georges Lemaître circa 1930

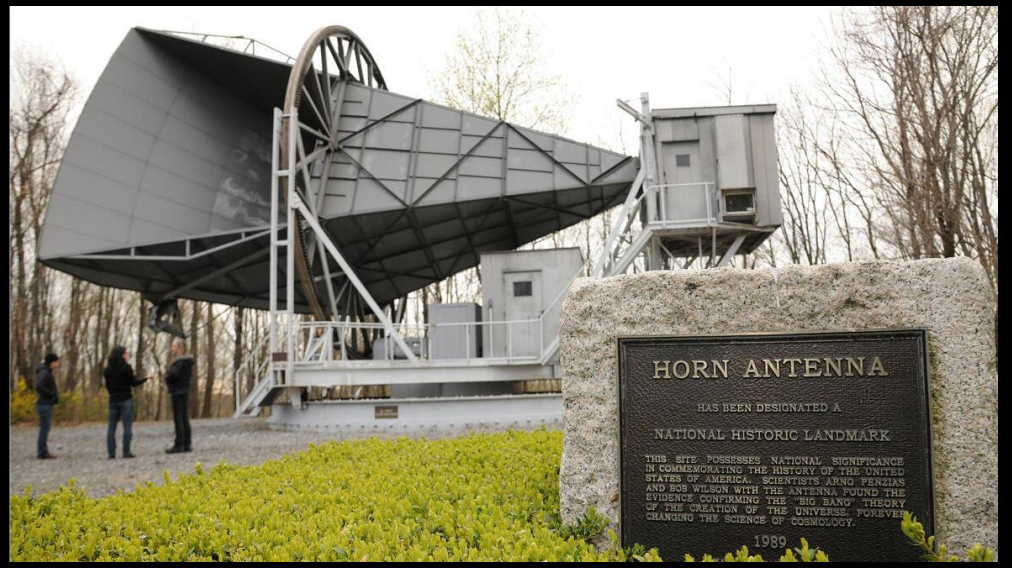
Edwin Hubbe circa 1930



In an expanding Universe, every galaxy moves away from every other galaxy, like points on an expanding balloon. There is no common center to the expansion.

The Big Bang Theory (no.. not that one...)

In 1964, Penzias & Wilson discovered (accidentally) a background of microwave radiation, that could only be due to a hot BIG BANG.

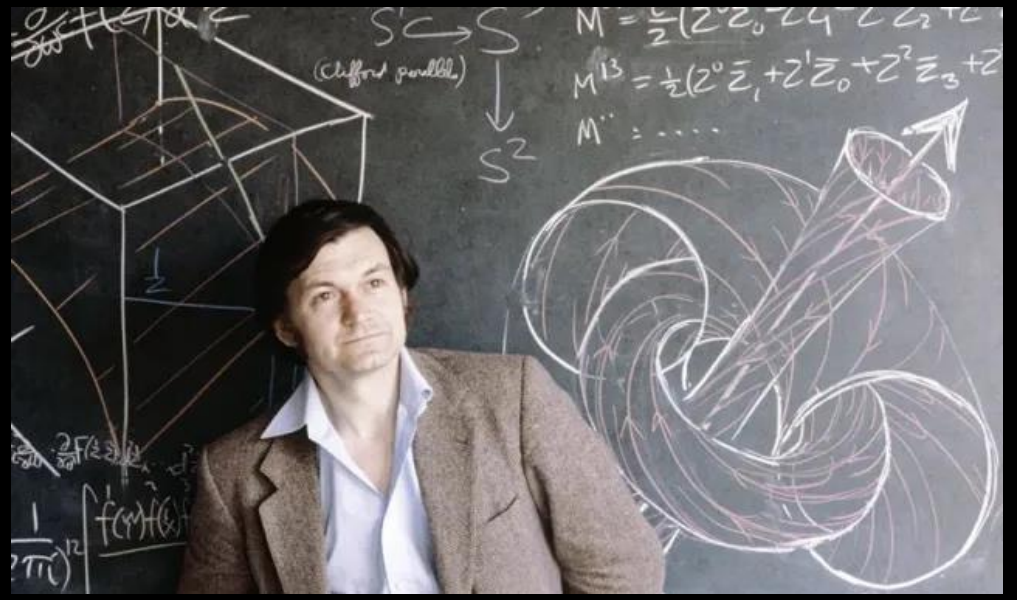


The Horn Antenna at Bell Labs in New Jersey.

In 1970, Hawking & Penrose publish their 'singularity theorems', showing mathematically that the Universe must have begun as a space-time singularity.

Arno Penzias & Robert Wilson

Stephen Hawking & Roger Penrose



Roger Penrose in the 1970's.


The Big Bang is Science!

Dark Matter (1933, 1970)

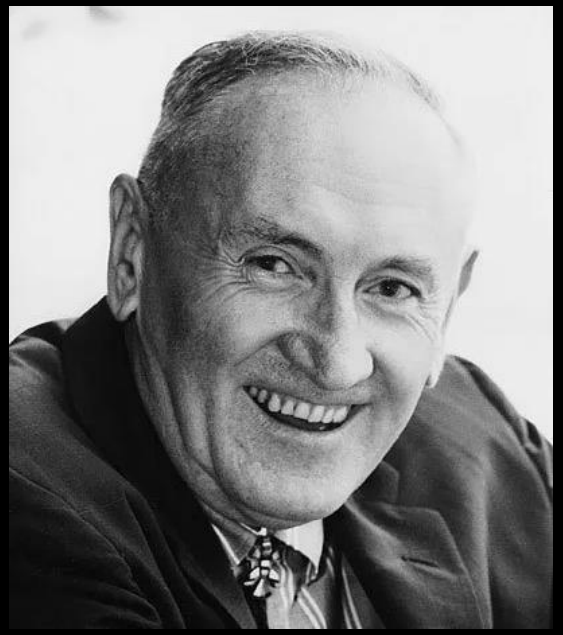
In 1933, Zwicky observed that the galaxies in the Coma Cluster (a galaxy cluster) were moving much faster than could theoretically be explained.

The cluster must contain more mass than can visibly be seen.

In 1970, Vera Rubin made more conclusive measurements of the rotation of spiral galaxies; showing that they must contain around ten times the mass that can be observed.

The Coma Cluster.

Vera Rubin, approx. 1970.



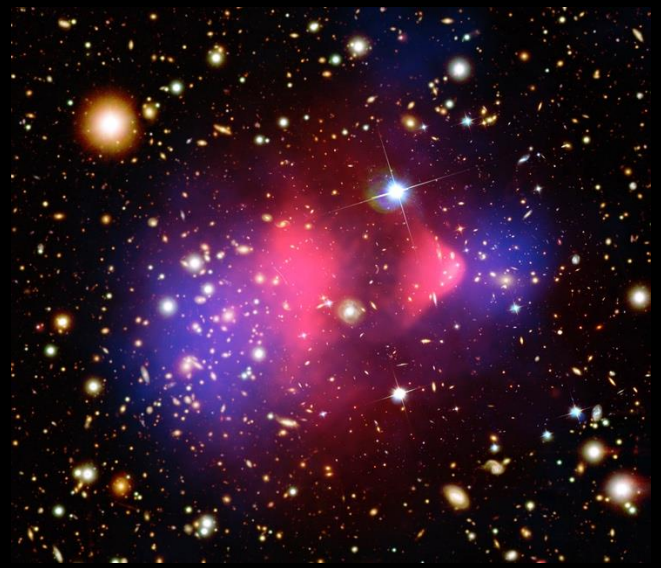
Fritz Zwicky (1898-1974).

Dark Matter (1933, 1970)

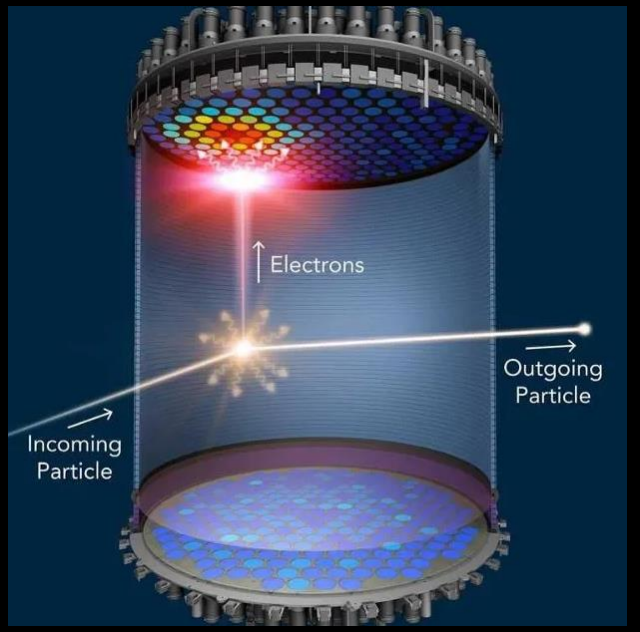
Dark Matter is invisible, passes practically uninterrupted through ordinary matter, and isn't affected my magnetic or electric fields...

We know it exists due to it's gravitational impact on the matter around it.

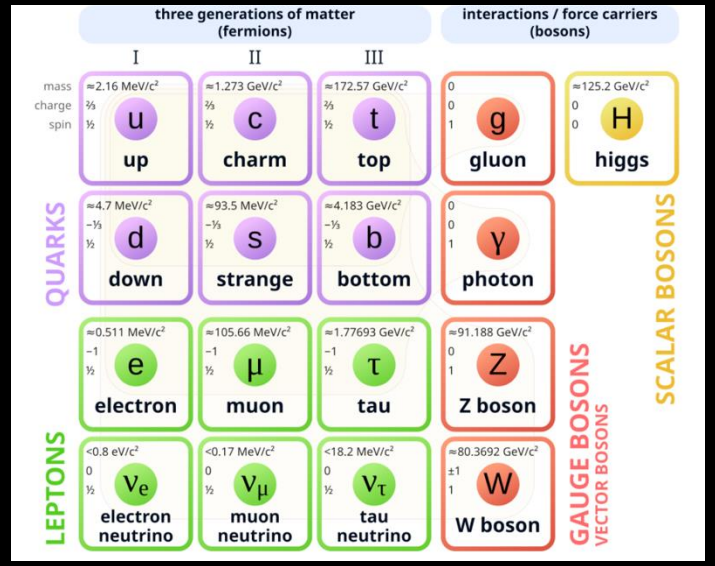
We have almost no idea what it is, at the level of elementary particles.



The Bullet Cluster.

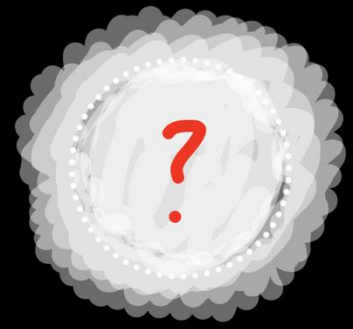


The XENON Experiment.



The Standard Model of Elementary Particles.

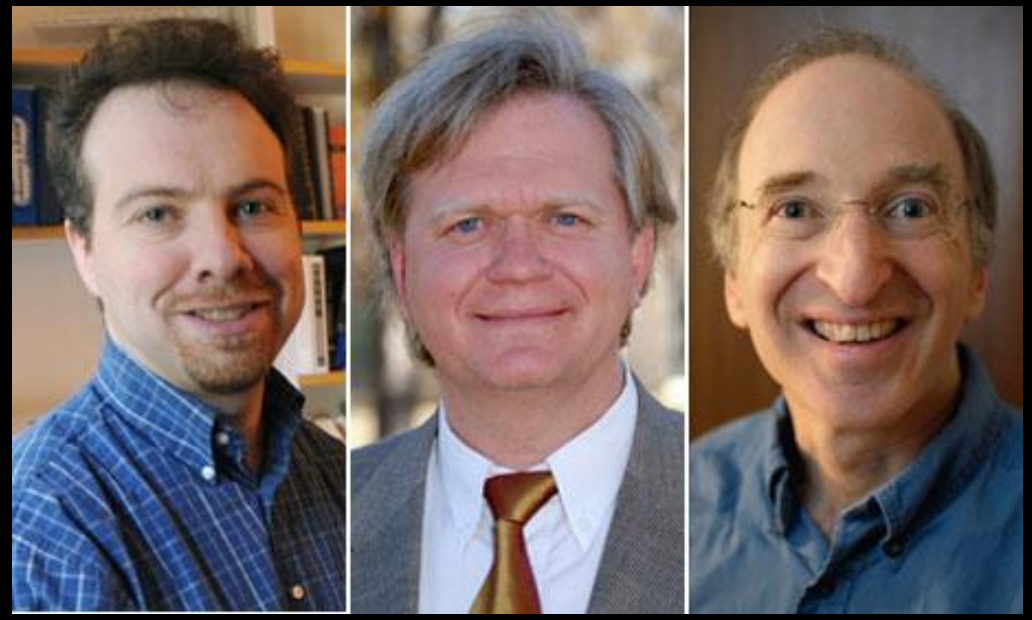
+



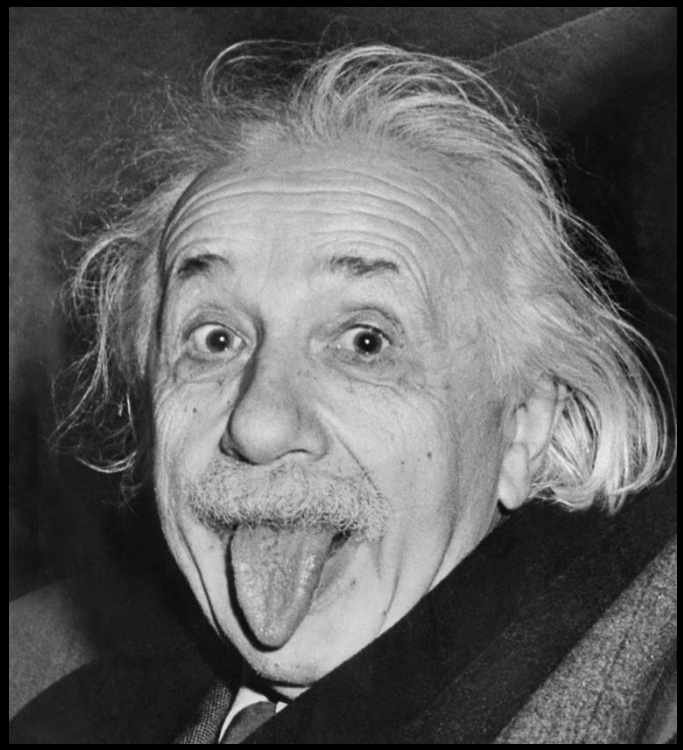
Dark Energy (1998)

By measuring the speeds of distant galaxies moving away from us, scientists were established that the expansion of the Universe is acceleration.

Mathematically… This acceleration is provided precisely by Einstein's Cosmological Constant.



Adam Riess, Brian Schmidt, and Saul Perlmutter. Winners of the 2011 Nobel Prize in Physics, for their contributions to the discovery of *Dark Energy*.



Einstein was right again!

2026 – State of the Field

Known Knowns:

- The Earth and other planets orbit the Sun.
- The Sun is just one of many Stars that form the Milky Way galaxy, and the Milky Way itself is one of many galaxies in the Universe.
- The Universe began with a hot Big Bang around 13.8 billion years ago.
- Galaxies are held together by an invisible but massive form of matter we call *Dark Matter*.

Known Unknowns:

- What is the particle nature of dark matter?
- What is the nature of dark energy?
- Is the Universe finite or infinite?

Unknown Unknowns:

- These will only be known in hindsight!

MCG+07-07-072

Why do we care?

Why do we care?

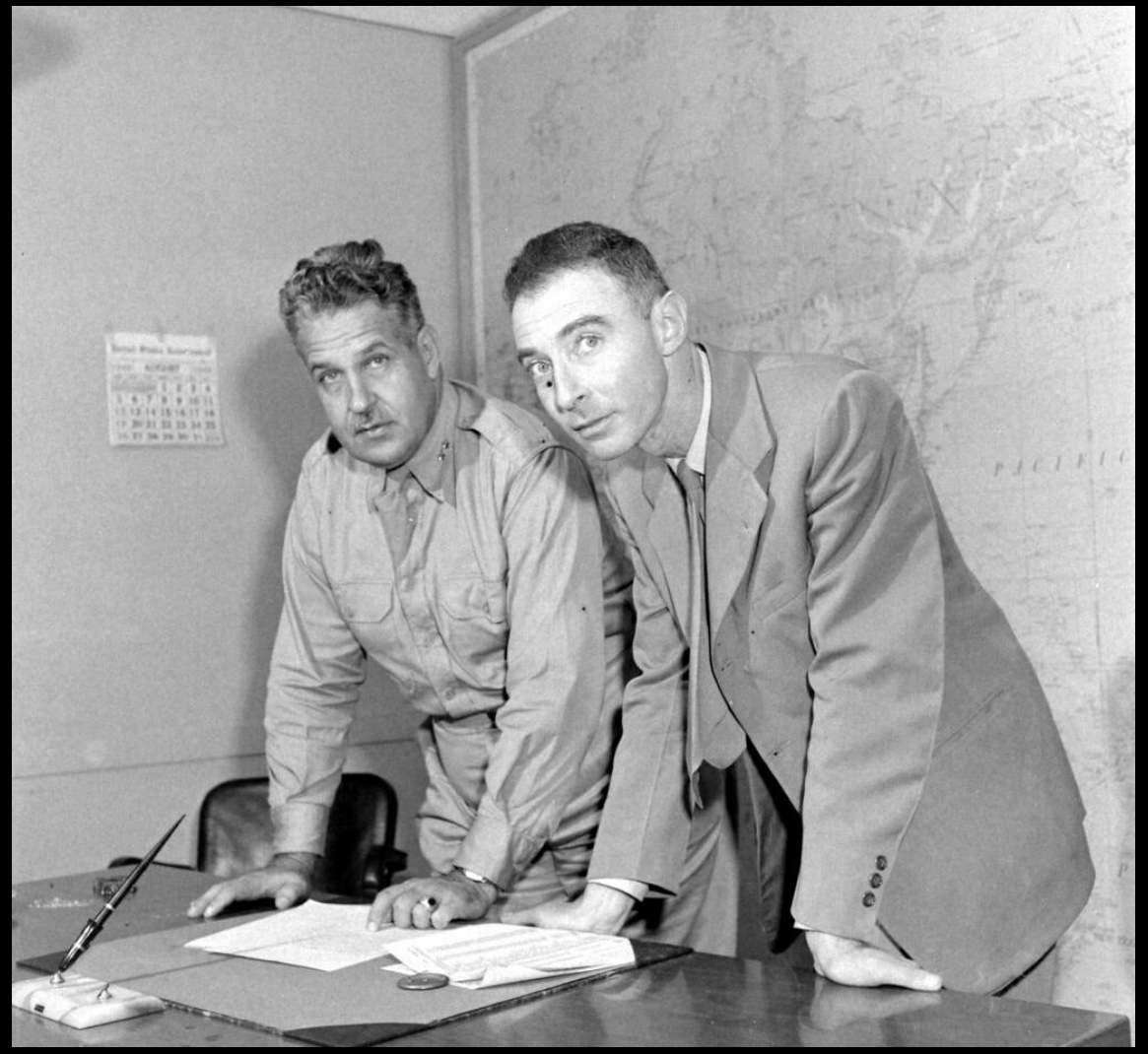
It’s in our DNA!

Questions!

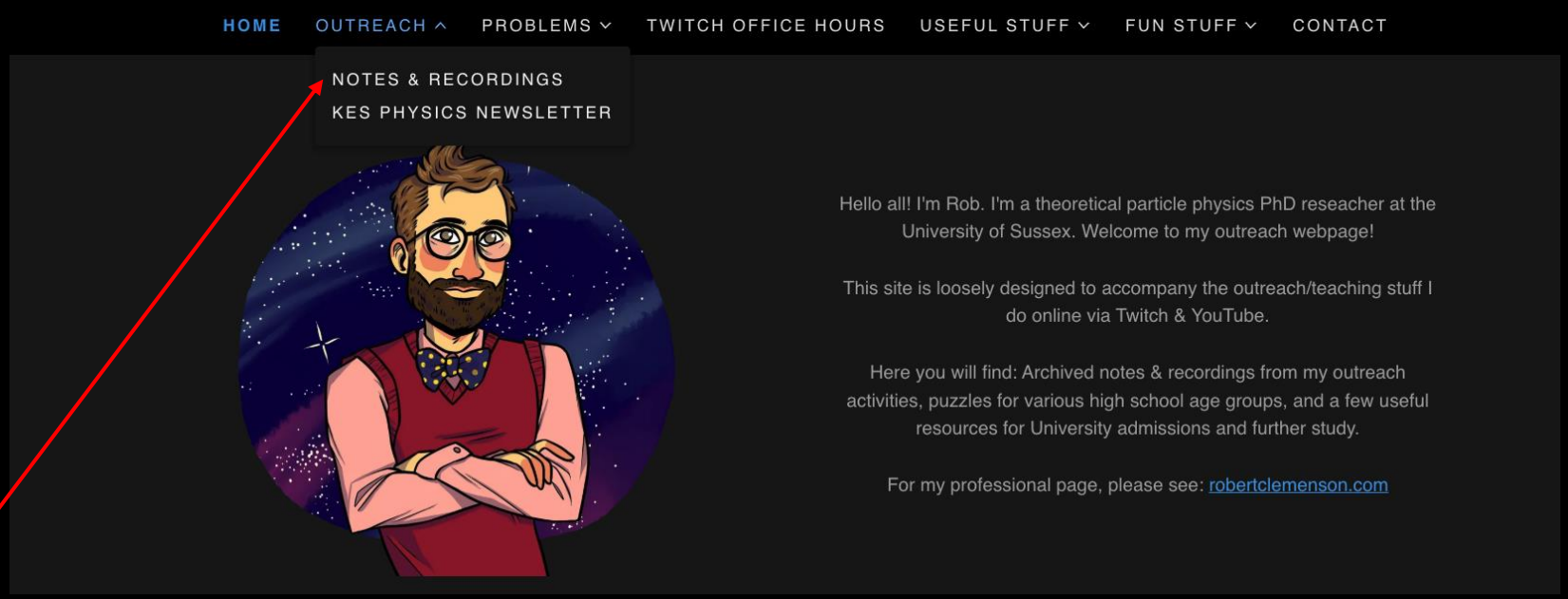
Coming Up…

The Manhattan Project: History and Physics

Southend History Club, date TBC @
The Beecroft Gallery Lecture Theatre



Lecture Slides



These lecture slides are available on my outreach website:

CosmicConundra.com