Cosmos

God the Geometer
Bible Moralisée
13th Century CE

This session will consider how science has discovered the universe – how it began, what it is made of, where it is going.

The word cosmos means much the same thing as universe. However, it derives from the Greek verb *cosmein* meaning to order or arrange. Thus it means the universe as an embodiment of order. The word *cosmein* was also used to arrange the hair and thus led to the word "cosmetic." Thus cosmos might also meant the universe as an embodiment of order and beauty.

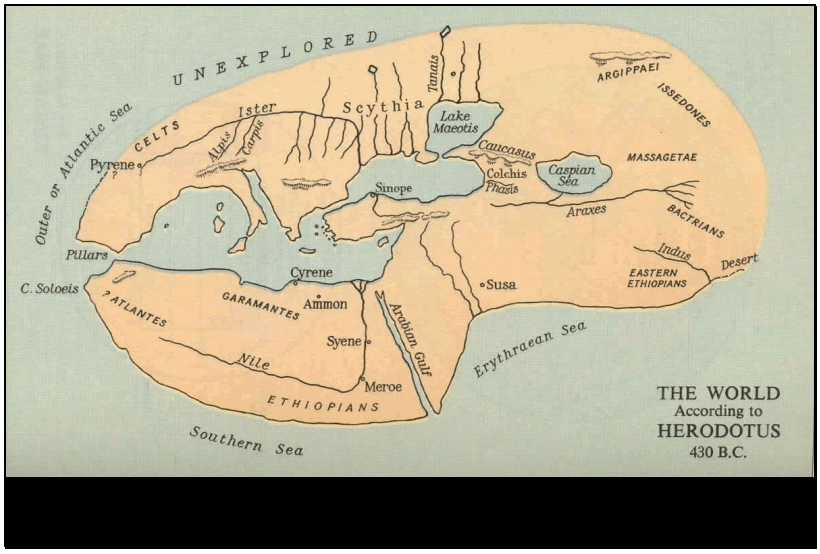
This illustration from a medieval Bible shows God determining the measurements of the cosmos. Everything – earth sun moon stars - is contained in a single geode. Above the illustration is written "Ici crie Dex ciel et terre soleil et lune et toz elemenz" (Here God creates the heavens and the earth, the sun and the moon, and all the elements).

Like the sun and the moon the earth in this medieval illustration is roughly spherical. Although some early human beings may have considered the earth as a flat disc, for more than 2500 years we have thought of the world as a sphere. In the 6th Century BCE, Pythagoras considered the Earth to be spherical because this was the first of the perfect solid shapes.

Nebra Sky Disk

This bronze disk (about 12 inches in diameter) dating back to 1600 BCE was found in Germany. The inlaid gold symbols appear to represent the sun, moon and stars. The arc at the right may represent the angle between the rising or setting of the sun in winter and summer. What the lower arc represents is not known.

Human beings have forever wondered about their place in the universe. They paid attention to the sky, watched the phases of the moon, and determined the changes in the sun from winter to summer. This sky disk is but one of many prehistoric representations of the heavens. Monuments such as Stonehenge were built using knowledge of the solstices. Many ancient myths may perhaps be related to how the heavens change with time.



Beneath the heavens was the world wherein we lived. Was this just a flat disk floating on a sea?

This map shows the world as understood by Herodotus (484-425 BCE). The map was put together based on the geographic descriptions in his *Histories.* He was born in Helicarnassus on the Western coast of present-day Turkey and lived much of his life in Athens. Greek maps were

made for people who traveled by boat. Thus the rivers are prominent – the Ister is the modern Danube.

In Book IV of the *Histories*, Herodotus recounts the voyage made by some Phoenicians around the continent of Africa:

> As for Libya [Herodotus' name for Africa], we know it to be washed on all sides by the sea, except where it is attached to Asia. This discovery was first made by Necos, the Egyptian king, who on desisting from the canal which he had begun between the Nile and the Arabian gulf, sent to sea a number of ships manned by Phoenicians, with orders to make for the Pillars of Hercules, and return to Egypt through them, and by the Mediterranean. The Phoenicians took their departure from Egypt by way of the Erythraean sea [Indian Ocean], and so sailed into the southern ocean. When autumn came, they went ashore, wherever they might happen to be, and having sown a tract of land with corn, waited until the grain was fit to cut. Having reaped it, they again set sail; and thus it came to pass that two whole years went by, and it was not till the third year that they doubled the Pillars of Hercules, and made good their voyage home. On their return, they declared — I for my part do not believe them, but perhaps others may — that in sailing round Libya they had the sun upon their right hand. In this way was the extent of Libya first discovered.

Though Herodotus did not believe the Phoenicians, their report is one of the first pieces of evidence that the earth is spherical rather than flat. In the southern hemisphere the sun is in the north. The sun would be on their right when the traveled westward below the equator.

Small bronze statue of Necho II

Necho II (610-595 BCE)

Necho II was an ambitious king of Egypt. He allied the Egyptians with the Assyrians against Babylon and defeated the Israelites at Megiddo (later to be known as Armageddon). He also tried to make a canal between the Nile and the Red Sea.

He commissioned some Phoenician sailors to journey around the continent of Africa from the Red Sea to the Pillars of Hercules. They reported that as they voyaged round the Cape of Good Hope the sun was on their right, i.e. to the north.

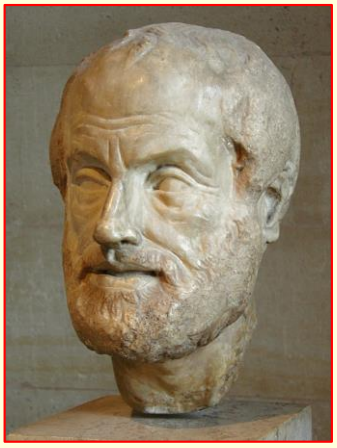
Aristotle's *On the Heavens* (*De Caelo*), 350 BCE

Aristotle (384-322 BCE) concluded that the Earth was spherical for both theoretical and experiential reasons:

(i) the element earth seeks itself and therefore by convergence all portions of the earth will come together to form a sphere.

(ii) there are stars seen in the south that are not seen in the north.

(iii) the shadow of the earth on the moon during a lunar eclipse has a circular edge



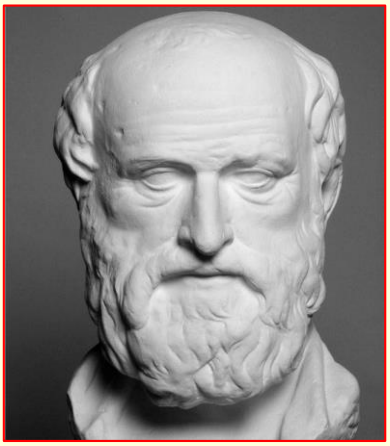
Roman marble copy of Greek bronze of Aristotle, Louvre

Aristotle's Physics and Astronomy

There are four elements – earth, water, air and fire. Earth and Water tend to fall whereas Air and Fire tend to rise. Thus the universe should contain earth at its center surrounded by concentric spheres of water, air and fire. However, because this system was subject to change, the earth had in part been raised out of the water. The stars were located in the fifth element – the aether.

Two kinds of stars could be observed – fixed and the wandering ("planet" from Greek *planao* wander). Aristotle located these in the aether. To keep them from falling he embedded them in concentric crystalline spheres. The fixed stars were in the outermost sphere. The sun, moon and all the wandering planets were each located in their own sphere. The sphere of the moon and everything above it were perfect and not subject to change or corruption.

Aristarchus (310-220 BCE) suggested that the wandering stars might revolve around the sun. But this did not make sense in Aristotelian physics, and Aristarchus was ignored.

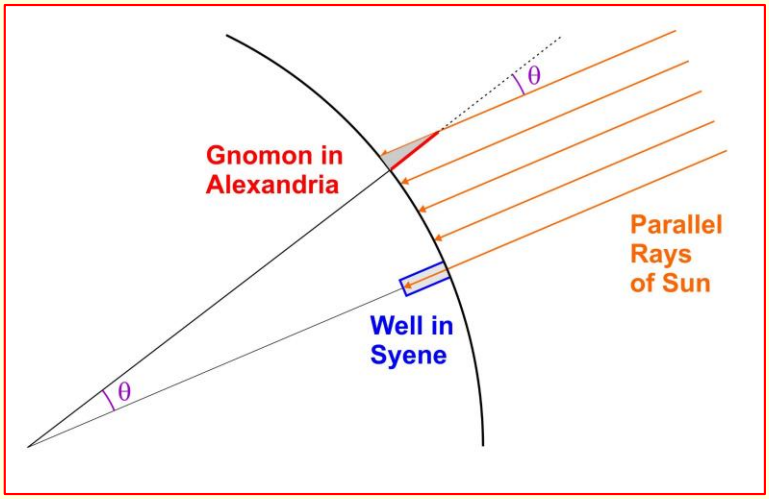


Possible portrait of Eratosthenes

Eratosthenes (276–194 BCE)

Born in Cyrene (part of present-day Libya), Eratosthenes studied in Athens and then became the head of the great Library of Alexandria. As a mathematician he invented a way to discover prime numbers. As a geographer he proposed the idea of longitude. He is most famous for measuring the circumference of the earth.

Late in life he became blind and he is reported to have starved himself to death in despair.



Eratosthenes (276-194 BCE), the chief librarian in Alexandria, heard that at the summer solstice the buildings in Syene (present-day Aswan) cast no shadow, and if one looked down a deep well one could see the sun reflected by the water. Aswan (24.0 degrees latitude) is located very close to the Tropic of Cancer (23.4 degrees). He measured the angle at which the sun's rays cast a shadow in Alexandria on the summer solstice as 7.2 degrees. This meant that the distance from Alexandria to Syene was 7.2/360 the circumference of the Earth. In order to get the distance to Syene, Eratosthenes is supposed to have employed bematists (Greek *bema*, pace), surveyors who measured distances in paces. Alexander had used these in his various expeditions. The distance was 5000 stadia. A stadion is just less than one eighth of a mile (a furlong). If one takes the distance as 185 meters Eratosthenes' calculation gives 46250 km which is about 15% longer than the actual 40008 km. Also, the North South distance between Alexandria and Syene is less than 5000 stadia since Syene is slightly East of Alexandria.

The results of Erastothenes were replicated using similar measurements by Posidonius about a century later based on the distance between Rhodes and Alexandria. Unfortunately his estimate of the distance was too short and his calculation of circumference gave 29000 km – much shorter than the actual distance. Ptolemy used this measurement in his *Geography*. Christopher Columbus predicted that the distance to the Indies from Spain was therefore about 4000 km. If he had known it was four times this distance he would not have set sail – he could only take provisions for the shorter voyage.

Ptolemy (100-170 CE)

15th Century Florentine map of the world based on the coordinates described in Ptolemy's *Geography*

Ptolemy was an astronomer and geographer who lived in Alexandria.

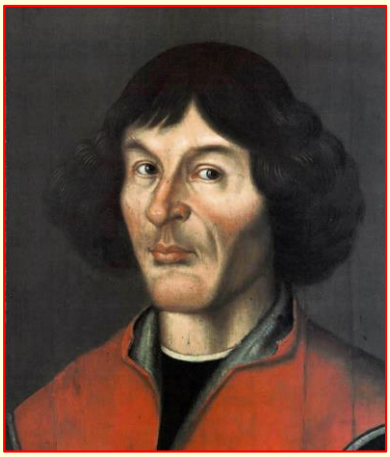
He described the geography of the known world.

He followed Aristotle's geocentric view of the universe, but made more exact models of the paths of wandering stars, using epicycles to explain their deviances from perfect circularity.

As the map demonstrates, Ptolemy's geography was very accurate. His astronomy was also accurate in its ability to predict the locations and movements of the stars. However, it failed to explain why they moved in the way they did.

Nicolas Copernicus (1473-1543)

Copernicus studied astronomy and mathematics in Poland. He then spent several years in Italy before returning to the University of Warmia. He decided that a heliocentric model of the universe would better explain the planetary motions than the geocentric model of Aristotle and Ptolemy. However, for fear that it might be condemned as heresy, he did not publish his book *The Revolutions of the Heavenly Spheres* until he was close to death.



Anonymous portrait in Turun, 1580

Copernicus was a brilliant astronomer. He correctly judged that the Church would not easily agree to his new conception of the universe.

Tycho Brahe (1546-1601)

Tycho Brahe was a Danish nobleman. He lost his nose in a fencing duel during his studies at the University of Rostock. He went on to become the last of the great naked-eye astronomers, accumulating an immense set of data on the motions of the planets. He also observed the sudden appearance of a supernova in 1572. He showed that this was more distant than the moon. This refuted the Aristotelian concept of an unchanging supralunary universe. Towards the end of his life he taught Johannes Kepler (1571-1630) in Prague

If you look closely at the engraving you can see the edge of Brahe's brass nasal prosthesis.

Johannes Kepler was the astronomer who found that the orbits of the planets were elliptical rather than circular. This phenomenon remained unexplained until the work of Newton.

Giordano Bruno (1548-1600)

Born near Naples, he entered the Dominican order but was accused of heresy and forced to flee. He taught philosophy at various cities in Europe, supporting the Copernican view of the universe, but having a more mystical view of physics than other scientists of his era. He was arraigned before the Roman Inquisition, found guilty of heresy and burned at the stake in the Campo dei Fiori in Rome.

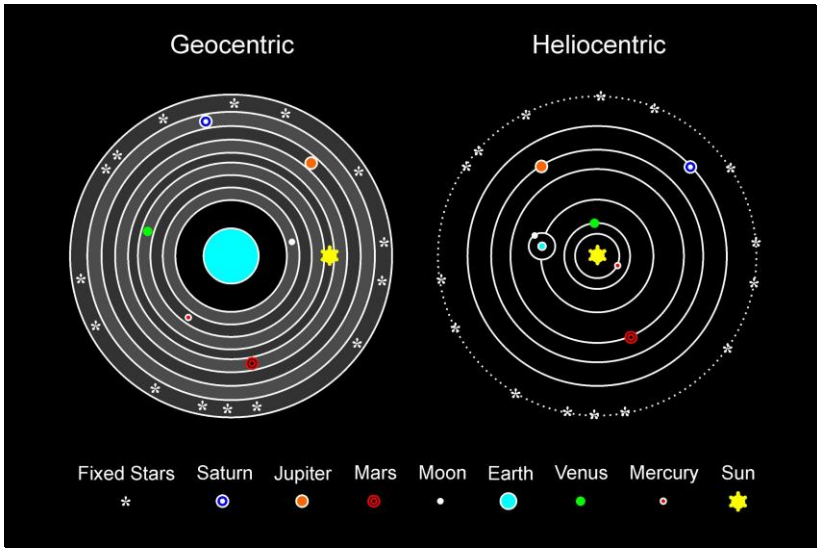
The illustration shows the statue erected in the Campo dei Fiori in 1889 in honor of Giordano Bruno and despite the opposition of the Vatican.

This photograph shows the Campo dei Fiori. The audio clip is from a poem by 1994 Heather McHugh entitled *What He Thought* The poem recounts an exchange visit of American poets to Italy. Their final dinner is in a restaurant on the Campo dei Fiori. The poem ends:

For our parting evening then
our host chose something in a family restaurant, and there
we sat and chatted, sat and chewed,
till, sensible it was our last
big chance to be poetic, make
our mark, one of us asked
"What's poetry?
Is it the fruits and vegetables
and marketplace of Campo dei Fiori or
the statue there?" Because I was
the glib one, I identified the answer
instantly, I didn't have to think – "The truth
is both, it's both!" I blurted out. But that
was easy. That was easiest to say. What followed
taught me something about difficulty,
for our underestimated host spoke out
all of a sudden, with a rising passion, and he said:
The statue represents Giordano Bruno,
brought to be burned in the public square
because of his offence against
authority, which is to say
the Church. His crime was his belief
the universe does not revolve around
the human being: God is no
fixed point or central government but rather is
poured in waves, through all things. All things
move. "If God is not the soul itself, He is

the soul of the soul of the world." Such was
his heresy. The day they brought him
forth to die, they feared he might
incite the crowd (the man was famous
for his eloquence). And so his captors
placed upon his face
an iron mask, in which

he could not speak. That's
how they burned him. That is how
he died: without a word,
in front of everyone.
        And poetry –
(we'd all
put down our forks by now, to listen to
the man in gray; he went on
softly) –
                poetry is what
he thought, but did not say.



This slide shows the two competing theories of the universe at the time of Galileo. As well as the different orbits, the geocentric theory proposed that the planets were embedded in crystalline spheres whereas the heliocentric theory had no such spheres. One of the arguments of those opposed to the heliocentric theory was the lack of any explanation for how the planets kept their places if there were no such crystalline spheres.

In addition to these two theories, Tycho Brahe had proposed an additional model wherein the sun and moon revolved around the earth but the rest of the planets revolved around the sun.

Portrait by Ottavio Leoni, 1624

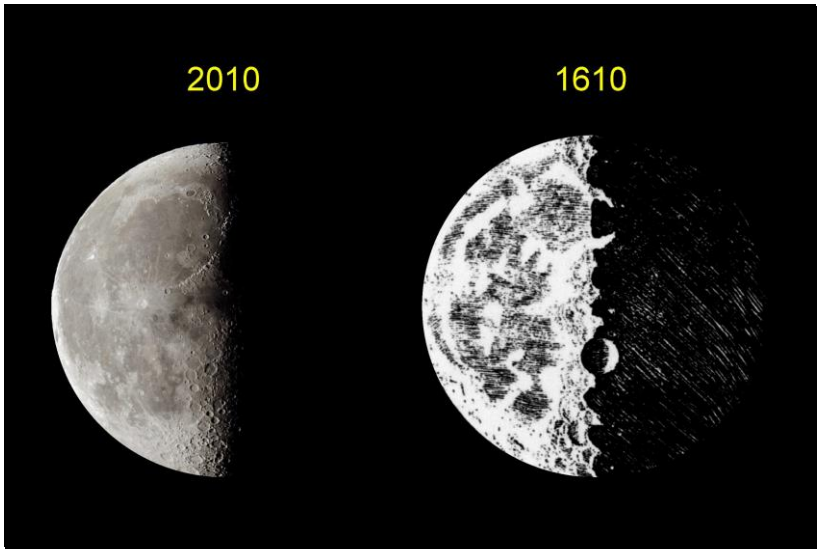
Galileo Galilei (1564-1642)

Galileo was the son of a lutenist in Pisa. He studied mathematics and physics and became a professor in Venice. In 1609 Galileo began to use the telescope which had just been invented in Holland. He was the first to use it to study the heavens. He reported three main findings:

(i) the moon's light is reflected, and its surface has craters and hills.

(ii) four moons rotate about the planet Jupiter

(iii) the planet Venus has phases just like the moon

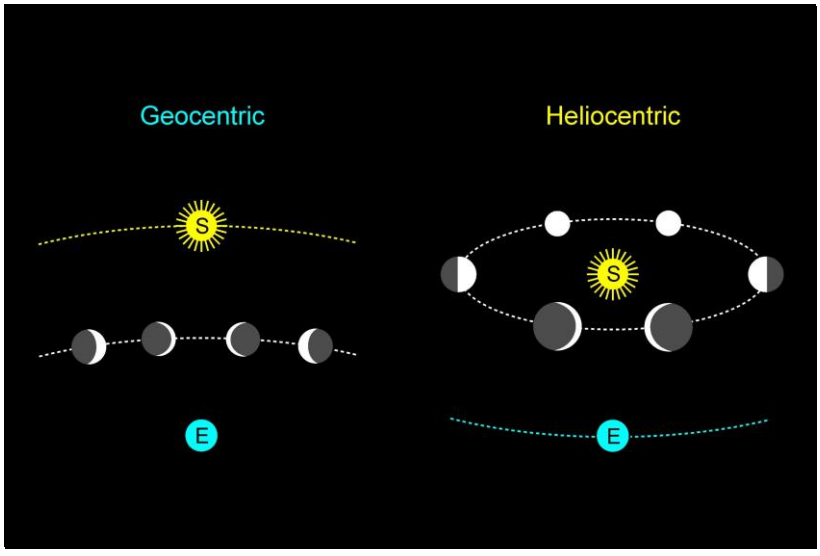


Galileo's description of the moon's surface as being flawed and of moon's light as being reflected contradicted the Aristotelian idea that the moon and everything above it were perfect. Change and deterioration only happened below the moon. .

Galileo's drawing of what he saw through the telescope is a little exaggerated from reality. Part of this was likely due to the limited field of view of his telescope, which prevented him from seeing more than a small part of the moon at any one time. His drawing clearly shows the craters and mountains. The shadows demonstrated that the light is reflected.

The 4 main moons of Jupiter were discovered almost simultaneously by Galileo and by Simon Marius, a German astronomer. Galileo called them the Medici stars, in an effort to gain the support of the Medici family in Florence. Marius gave them the names of those seduced by Jupiter – Io, Europa, Ganymede, Callisto.
The orbital times for these moons vary between 1.8 and 16.7 days. Thus Galileo could observe the moons in different positions on successive nights. The clip shows time-lapse photographs from the Juno spacecraft on its way to Jupiter. As the moons go behind the planet in relation to the sun (on the left in the photographs) they are briefly eclipsed. The music is appropriately majestic. This clip is extracted from a longer video:
https://www.space.com/33348-jupiter-moon-s-orbital-dance-humans-have-never-seen-this-video.html

The motions of these moons demonstrated that small celestial bodies orbited around larger bodies. This would be impossible if the larger bodies were embedded in a crystalline sphere.



If the planet Venus shone with its own light then it would appear circular at all times. Since it changes phase, the light is reflected

In the geocentric theory both Venus and the sun would orbit the Earth. If the light from Venus was indeed reflected from the sun then we should never be able to see a full circular view of the planet.

If the planets and the earth both orbited the sun, we should see the planet Venus go through phases just like the moon. Galileo found that the planet went through a full set of phases just like the moon. Galileo wrote in code to Kepler *Cynthiae figuras aemulatur mater amorum*. The mother of love (Venus) copies the forms of the Cynthia (the moon).

This is a clip form the movie *Galileo* based on the play by Bertolt Brecht. Galileo is played by Topol and his colleague Sagredo by Michael Gough. The episode dramatizes Galileo's discovery of the moons of Jupiter. The importance of the findings is clearly shown though, after Star Trek, the statement "I am a mathematician not a theologian" sounds more comic than insightful.

Sagredo is correct in his fears. A quotation from Machiavelli (a century before Galileo) is appropriate:

> It ought to be remembered that there is nothing more difficult to take in hand, more perilous to conduct, or more uncertain in its success, than to take the lead in the introduction of a new order of things. Because the innovator has for enemies all those who have done well under the old conditions, and lukewarm defenders in those who may do well under the new. This coolness arises partly from fear of the opponents, who have the laws on their side, and partly from the incredulity of men, who do not readily believe in new things until they have had a long experience of them.

The Trial of Galileo (1633)

Galileo was found guilty of "vehement heresy," and his books were placed on the Index. He was forced to publically abjure the idea that the earth moved around the sun. Legend has it that he said *Eppur si muove* (And yet it moves) under his breath after his recantation.

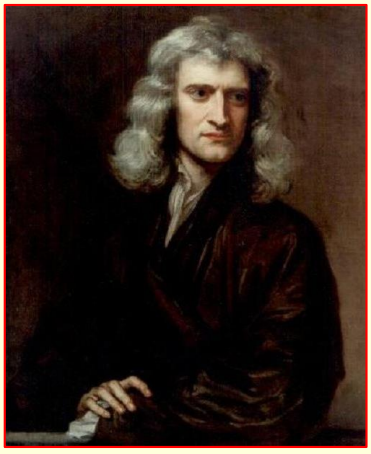
Galileo Facing the Roman Inquisition
Cristiano Banti, 1857

Why were Galileo's ideas found unacceptable by the Church?The key feature of the geocentric system was that it was centered upon the Earth. God looked down from the Heavens upon his special creation. This idea was completely disrupted by the Copernican theory.

In Brecht's play *Galileo*, this is expressed by an old cardinal:

> I am not just any old creature on any insignificant star briefly circling in no particular place. I am walking, with a firm step, on a fixed earth. It is motionless, it is the center of the universe. I am at the center and the eye of the Creator falls upon me and me alone.

However, once Galileo was arraigned before the Inquisition, there was little doubt about the outcome. As pointed out by Giorgio de Santillana (1955), "In a theological state, man is not innocent until proved guilty. Much the reverse, he is presumed guilty and God or the authorities alone can know how much." Galileo was condemned to prison, though this became house-arrest.



Portrait by Geoffrey Kneller, 1689

Isaac Newton (1642-1727)

In 1687, Newton published his *Philosophiæ Naturalis Principia Mathematica*, wherein he proposed the law of universal gravitation: that all masses attract each other with a force that varies directly with the product of their masses and inversely with the square of the distance between them. Newton used the force of gravity to explain Kepler's elliptical planetary orbits and the perturbations that occurred in these orbits as a result of the gravitational attraction between one planet and another. He also explained the diurnal motion of the tides under the gravitational attraction of the moon.

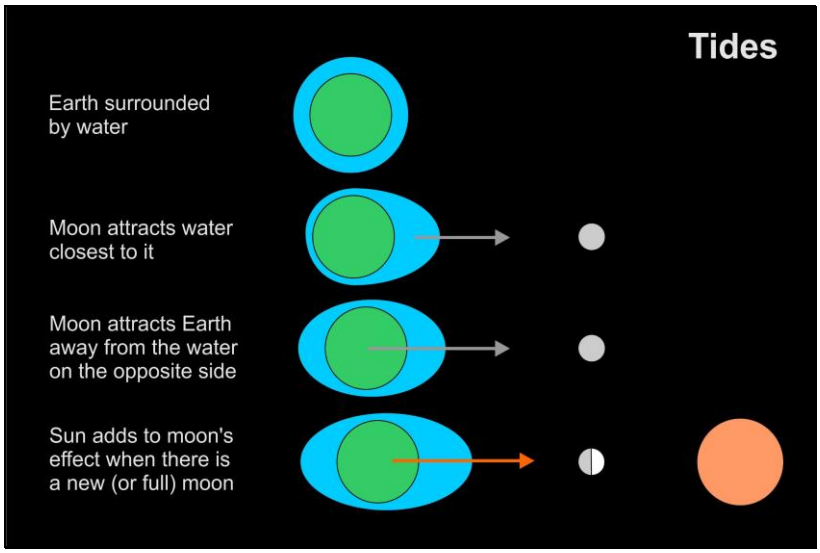
One of the Church's criticisms of the Copernican system was that it was not proven. This fails to understand the process of science wherein nothing is ever proven. Rather science accepts as true that which fails to be disproven when repeatedly tested.

Nevertheless, Galileo's findings did not definitively disprove the geocentric system. Even the phases of Venus might be explained by the system of Tycho Brahe wherein Venus revolves around the Sun which itself revolved around the Earth. Why did the planets revolve around the sun? Why were the orbits actually elliptical rather than circular as shown by Kepler? It was not until Isaac Newton that the orbits of the planets around the sun were accounted for by the theory of gravitation. And this theory was itself tested by the idea that planets attracted planets thus slightly perturbing their orbits around the sun.

Gravity also accounted for the tides. Galileo had attempted to explain the tides as caused by the rotation of the earth, but this had completely failed to account for the fact that there were two tides each day.

The world was duly astonished by the genius of Newton – Alexander Pope exclaimed:

Nature and nature's laws lay hid in night;
God said "Let Newton be" and all was light.



In 1616 Galileo had attempted to explain the tides by the rotation of the Earth. The major problem was the fact that there were two tides a day. Galileo attributed this the oceans being set in motion by the Earth's rotation and then sloshing back and forth like a pendulum. He did not convince anyone. No matter. The tides in the Mediterranean region are very small.

Newton could explain the tides using the gravitational attraction between the moon and the earth. Since this varies with distance the moon pulls the closest water closer to it, and also pulls the Earth away from the water furthest away from it. During one rotation of the Earth there are

therefore 2 high tides and 2 neap tides. When the moon is aligned with the sun at new moon (illustrated) at the bottom the gravitational attractions of both moon and sun work together. A similar effect occurs with a full moon when the moon is on the opposite side of the Earth to the sun. The tide at the time of the new or full moon is called the spring tide, though it does not necessarily occur in spring.

The tides are also affected by the shape of the sea bed, and the inclination of the moon's orbit around the Earth.

Tide in the Bay of Fundy

Time-lapse photography of tide in Bay of Fundy recorded at Hall's Harbour Nova Scotia: https://www.youtube.com/watch?v=rl0b6L2tDko

Note that there are two high tides within the daylight hours.
Fundy's tides are the largest in the world, sometimes reaching 17 meters (56 feet). Ungava Bay in Northern Quebec also has a very large tide.

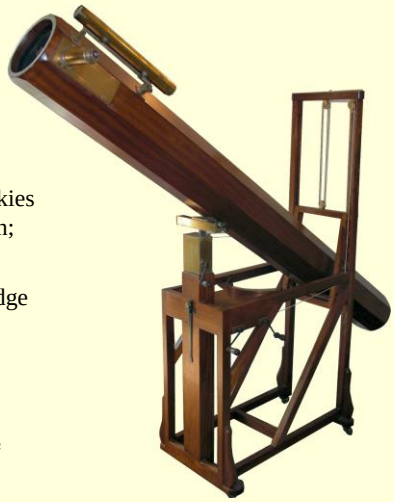
William Herschel (1738-1822)

Born in Hanover, Herschel emigrated to England at the age of nineteen. He was an accomplished musician and composed 24 symphonies and numerous concertos. In 1772 he became interested in astronomy and built himself a reflecting telescope. Thereafter he became a dedicated observer of the heavens. In 1781 he identified the planet Uranus. He also discovered the moons around Saturn and Uranus, and made an exhaustive catalogue of the stars and galaxies in the night sky.

Portrait by Lemuel Francis Abbott, 1785

Herschel's catalogue was expanded by his son John Herschel. The catalogue is still used today to identify galaxies.

Some Watcher of the Skies



Then felt I like some watcher of the skies
When a new planet swims into his ken;

read by Douglas Hodge

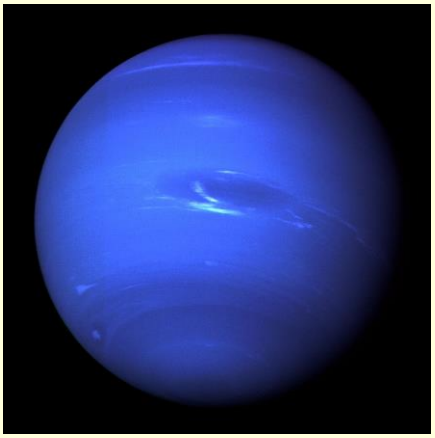
Adagio from Herschel's Oboe Concerto in C major.

John Keats' poem *On First Looking into Chapman's Homer* (1816) refers to Herschel's discovery of Uranus:

Much have I traveled in the realms of gold
And many goodly states and kingdoms seen;
Round many western islands have I been
Which bards in fealty to Apollo hold.
Oft of one wide expanse had I been told
That deep-browed Homer ruled as his demesne;
Yet never did I breathe its pure serene
Till I heard Chapman speak out loud and bold:
Then felt I like some watcher of the skies
When a new planet swims into his ken;
Or like stout Cortez when with eagle eyes
He stared at the Pacific—and all his men
Looked at each other with a wild surmise—
Silent, upon a peak in Darien.

Discovery of Neptune

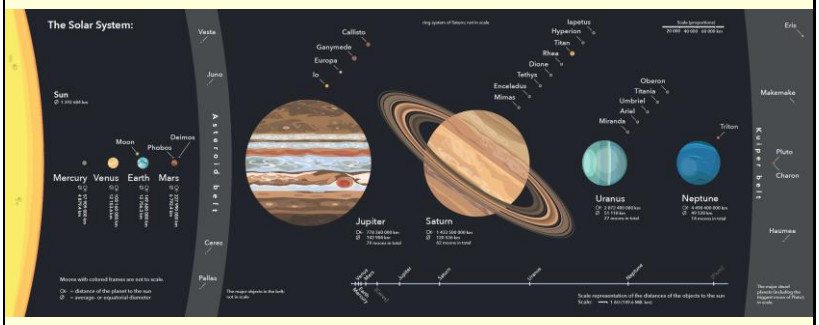
The French mathematician and astronomer Urbain Le Verrier noted that the orbit of Uranus was perturbed from what would be expected. In 1846 he calculated that this must be due to the gravitational attraction of another planet. He sent the coordinates to Johann Gottfried Galle at the Berlin observatory and Galle found the planet Neptune almost exactly where it had been predicted.



Neptune as viewed by Voyager 2 space probe, 1989

Newton's theories of gravitation were thus able to predict what had not been seen before. This was powerful science.

Solar System



The planets Mercury, Venus,, Mars, Jupiter and Saturn, had been identified by ancient Babylonian astronomers in the 2nd millennium BCE. The moons of Jupiter were discovered in 1610 by Galileo. Uranus was identified by William Herschel in 1781. Neptune was found in 1846 by Galle and le Verrier. Pluto was seen in 1930by Clyde Tombaugh but relegated to "dwarf planet" in 2006.

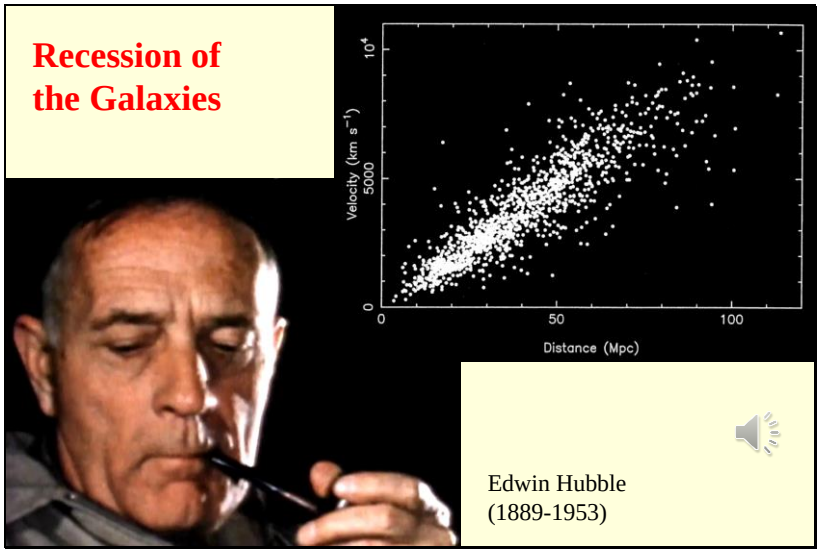
Illustration from Wikipedia:
https://en.wikipedia.org/wiki/File:Solar-System.pdf

For the Babylonians the number 7 was magical. The five identified planets together with the moon and the sun made 7 heavenly bodies.

Possible mnemonic: My very educated mother just served us nachos.

With the improvement in telescopes, it became apparent that some stars in the night sky were actually large groups of stars – galaxies. The word comes from the Greek *galactias* milky, in reference to our own galaxy – the Milky Way.

The photograph of the Pinwheel Galaxy is from the Hubble orbital telescope, launched in 1990 and still in operation.

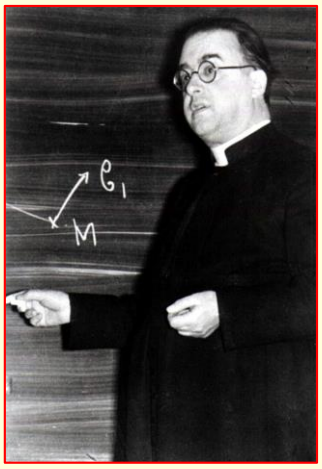


One of the intriguing facts about the galaxies is that they are moving away from us. The further they are away the faster they are moving. Edwin Hubble made these measurement sin the early 1920s. The speed of the galaxies was measured by the "red-shift" in the observed frequency of various lines (coming from different elements) in the light of the galaxies. This is like the Doppler shift in sound waves. The sound sample recorded a train's horn as it decreases in frequency when it moves away. Christian Doppler was a 19th Century Austrian physicist.

Combining Hubble's measurements with Einstein's theory of relativity and Lemaître's mathematics led physicists to postulate that the universe began almost 14 billion years ago with the explosion of a singularity and has been expanding ever since.

The beginning of the world from the point of view of quantum theory (1931).

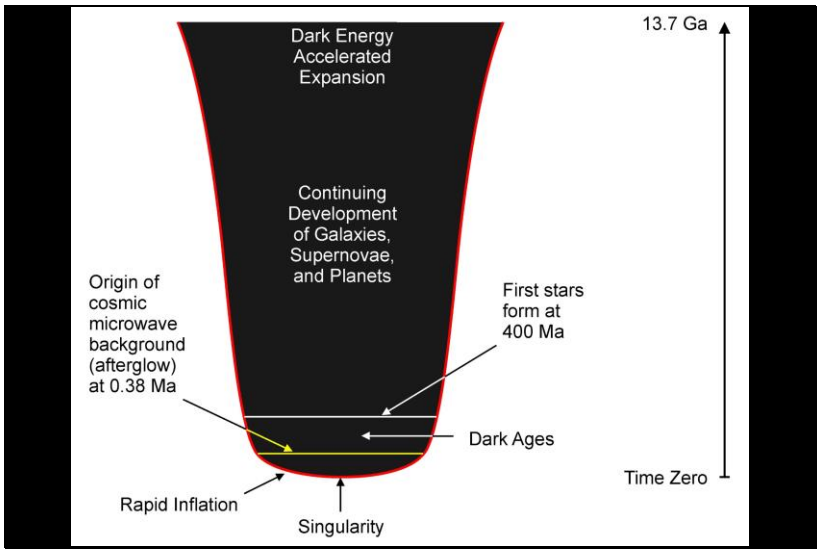
Clearly the initial quantum could not conceal in itself the whole course of evolution; but, according to the principle of indeterminacy, that is not necessary. Our world is now understood to be a world wherein something really happens; the whole story of the world need not have been written down in the first quantum like a song on the disc of a phonograph. The whole matter of the world must have been present at the beginning but the story it has to tell may be written step by step.



Georges Lemaître (1894-1966)

Lemaître was a Catholic priest who first described the Big Bang theory of the origin of the universe. He was triggered to study the expansion of the universe by his reading of the book of *Genesis*. That the universe was divinely created out of nothing (*ex nihilo*) is an essential part of the Judeo-Christian doctrine. Interestingly, in this quotation he tries to reconcile the ideas of determinism and free will.

The name "Big Bang Theory" came from Fred Hoyle in 1949. He rejected the theory, preferring the idea of a Steady State Universe. Today most physicists believe in the Big Bang

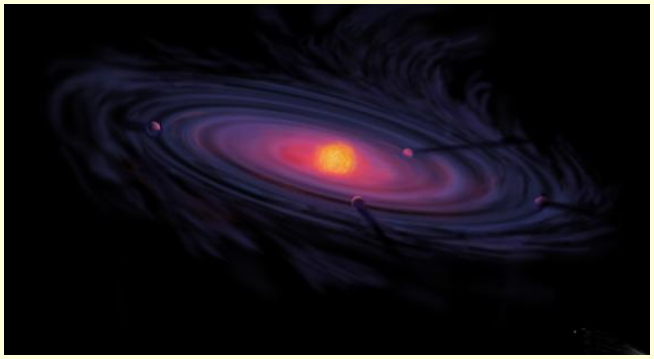


Our universe has not existed forever: the universe began 13.8 billion years ago. It began as a singularity – a point of tremendous density and temperature. In 1949, Fred Hoyle called the

explosion of this singularity the “Big Bang.” The term “began” may not be appropriate, since then there was no time. The singularity was a “now without a yesterday” (Lemaître, 1946).

Describing an object or event as a singularity means that it is unpredictable or unmeasurable because it is unlike anything else. The term was first used to describe a point in a mathematical function that cannot be differentiated, i.e. related to what precedes or follows it. For example there is a singularity in the function 1/x when x=0. As x approaches 0 from positive x, the function tends toward an infinitely large value. As it approaches 0 from the negative the function tends toward an infinitely small value.

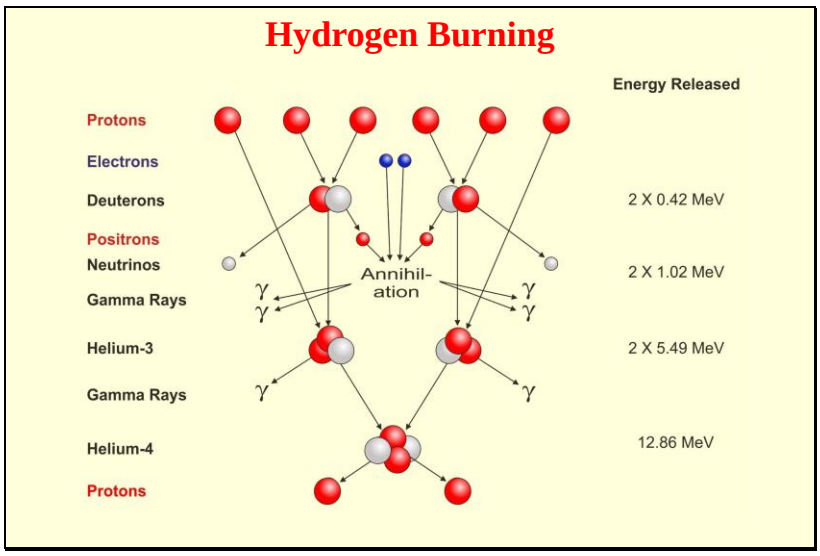
Planet Earth



The evolution of the universe may be compared to a display of fireworks that has just finished. A few red embers, ashes and smoke. Standing on an optimally cooling cinder, we see the gentle fading of the suns, and try to recall the vanished brilliance of creation. (Lemaître, 1946)

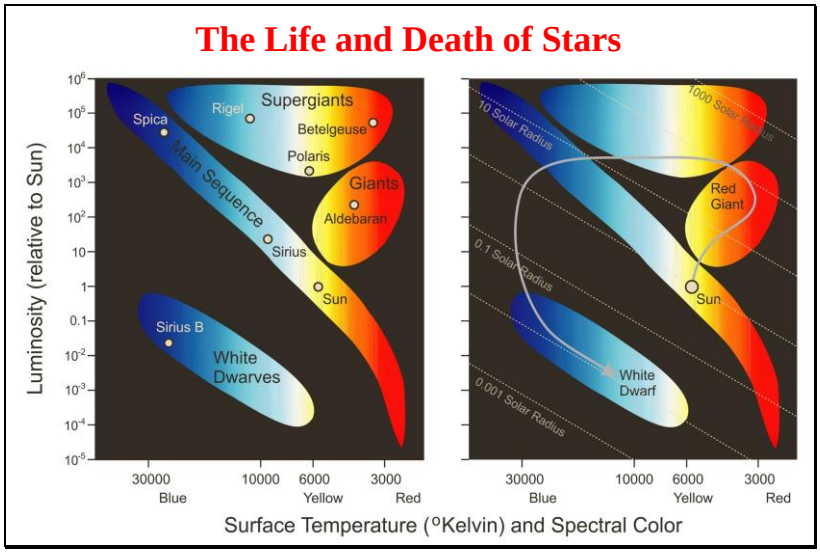
The quotation is from Georges Lemaître, the physicist-priest.

After the initial singularity had exploded, the particles fused to form hydrogen nuclei. These collapsed to form stars and galaxies. The gravitational collapse of stars led to the formation of heavier elements. Some of the collapsing stars exploded as supernovae scattering dust into space. Clouds of dust accumulated as a disc around other stars, and the dust accreted to form planets. The Earth began around 4.5 billion years ago.



With the new discoveries in atomic physics, scientists began to consider the processes that occur in stars. In 1920, Arthur Eddington proposed that stars generated energy from the fusion of hydrogen to form helium. Within a star the gravitational attraction was sufficient to overcome the electrostatic repulsion between protons (the nuclei of hydrogen atoms) and bring them together to form helium. Once close enough another force binds them together.

In most stars the kinetic energy of the particles and atoms counteracts the gravitational forces that bring them together.

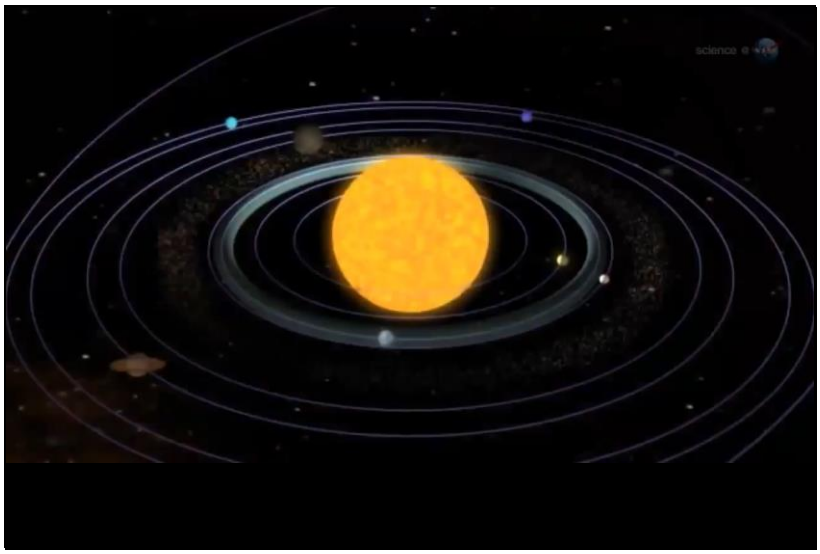


These diagrams represent the relations between the size of a star, its luminosity and its temperature. These diagrams were initially created in 1910 by Ejnar Hertzsprung and Henry Norris Russell and are often called Hertzsprung-Russell diagrams.

Most observed stars, and our own sun, fit in the area called the "Main Sequence." Larger stars burn at higher temperatures to balance out the increased gravitational attraction.

As the years go by, the core of the star comes to have more and more helium nuclei. This helium then begins to fuse into larger elements such as carbon (atomic number 6) nitrogen (7) and oxygen (8). Even more energy is created, the shell expands, and the star becomes a red giant. The shell may then explode as a "nova," scattering matter into space to give a planetary nebula, and leaving the core to collapses into a white dwarf star. This possible evolution is tracked in the right graph.

Other evolutions are possible. Instead of becoming a white dwarf, a star may collapse into a neutron star or into a black hole.



Both history and science can help us to predict the future.
So this is our present idea of how the Earth will end.

excerpted from a NASA video:
https://www.youtube.com/watch?v=_18ubTIfYbo

As our sun expands to become a red giant, its diameter will finally reach earth's orbit. The earth may thus be engulfed by its sun. However, by then the earth may have moved out to a more distant orbit under the force of the increased flow of particles coming from the red giant. This solar wind will also have stripped the earth of its atmosphere. The combined effects of the solar wind and the gravitational attraction of the earth will likely have caused the moon to disintegrate. Our original home in space will have become be a planet sans life, sans moon, sans everything. Where will humanity be? We may have long ceased to exist, having succumbed to disease, destroyed ourselves by war, or surrendered to a technology beyond our control. Or we may have survived and somehow moved to another home in the universe long before our planet's demise.

Earth's biosphere will be rendered sterile by the increased radiation from our expanding sun within 3.5 billion years from now, long before the estimated 7 billion years when the planet will finally be engulfed by a red giant sun.

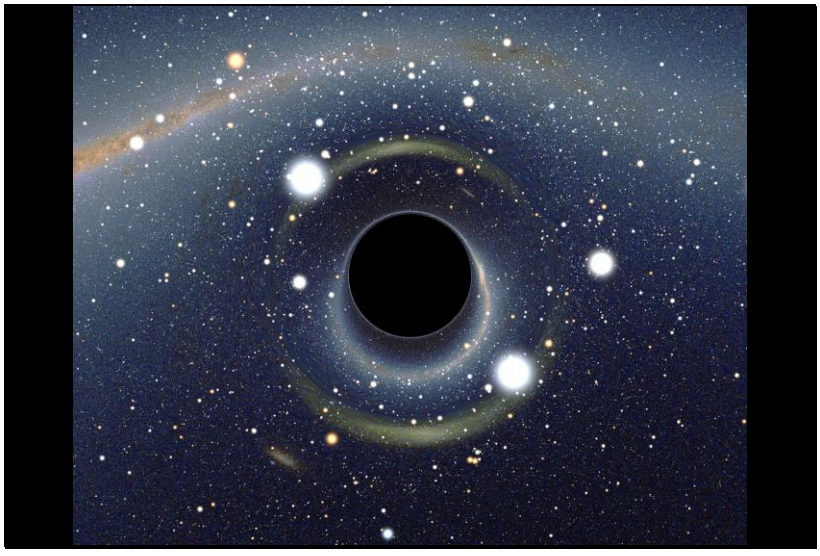
Stephen Hawking (1942-2018)

Hawking received his undergraduate education at Oxford University where he coxed the rowing team. He did graduate work at Cambridge, producing a thesis that argued for a singularity like a black hole as the origin of our expanding universe. In 1963 he was diagnosed with motor neuron disease (amyotrophic lateral sclerosis). As the disease progressed he became unable to speak and used a speech synthesizer to interact with others. In 1988 he published *A Brief History of Time from Big Bang to Black Holes.* Defying the usual prognosis for his disease, Hawking continued to work until age 76.

The median survival in amyotrophic lateral sclerosis is 3-5 years.
Quotes about *A Brief History of Time*:

the most popular book never read

Stephen Hawking has sold more books about physics than Madonna has sold books about sex.



Simulation of a Black Hole
https://commons.wikimedia.org/wiki/File:BH_LMC.png

The simulated black hole is place in front of the Large Magellanic Cloud. The gravitational lensing effect produces two enlarged but highly distorted views of the Cloud. Across the top, the Milky Way is distorted into an arc.

The idea that a star could collapse into itself because of the gravitational attraction between its constituents was initially proposed in 1783 by John Mitchell, an English parson. He called such an entity a "dark star." Because of the huge gravitation field no light could escape and the collapsed star could only be observed by its effects – tearing apart nearby dust clouds or distorting the paths of light (illustration). The idea of the dark star came back in the mid 20th Century, and the name "black hole" was coined. This was supposedly used by the American physicist Phillip Dicke, who likened the entity to the Black Hole of Calcutta – the prison where people entered but never left alive. Black Holes were extensively studied by Steven Hawking and Robert Penrose. They cannot be completely understood because our concepts of space and time are no longer valid. They are "singularities" – like that proposed as the origin of our universe

We have considered the end of the Earth.
Now perhaps we might also consider the end of the universe:
https://www.businessinsider.com/how-and-when-our-universe-will-end-2017-8

No one really understands the force that is causing the universe to expand.
One intriguing thing is that we are living at a time when we can observe other galaxies. If we live many million years in the future we would not be aware that there was a universe beyond our own galaxy.

Where wast thou when I laid the foundations of the earth? declare, if thou hast understanding.

Who hath laid the measures thereof, if thou knowest? or who hath stretched the line upon it?

Whereupon are the foundations thereof fastened? or who laid the corner stone thereof;

When the morning stars sang together, and all the sons of God shouted for joy? (*Job* 38: 4-7)

Ancient of Days
William Blake, 1794

Blake's *Ancient of Days* was the frontispiece for his book *Europe, A Prophecy*. Blake, who lived at the same time as Newton, considered himself a prophet who had been given insight into past and future. Blake was very critical of reductive scientific thought. He considered that Newton's science was blind to the truth that could be seen through the creative imagination.

The quotation is from the *Book of Jo*b. Physicists today claim that they have indeed measured the origins of the Earth.

However we still do not understand its future.