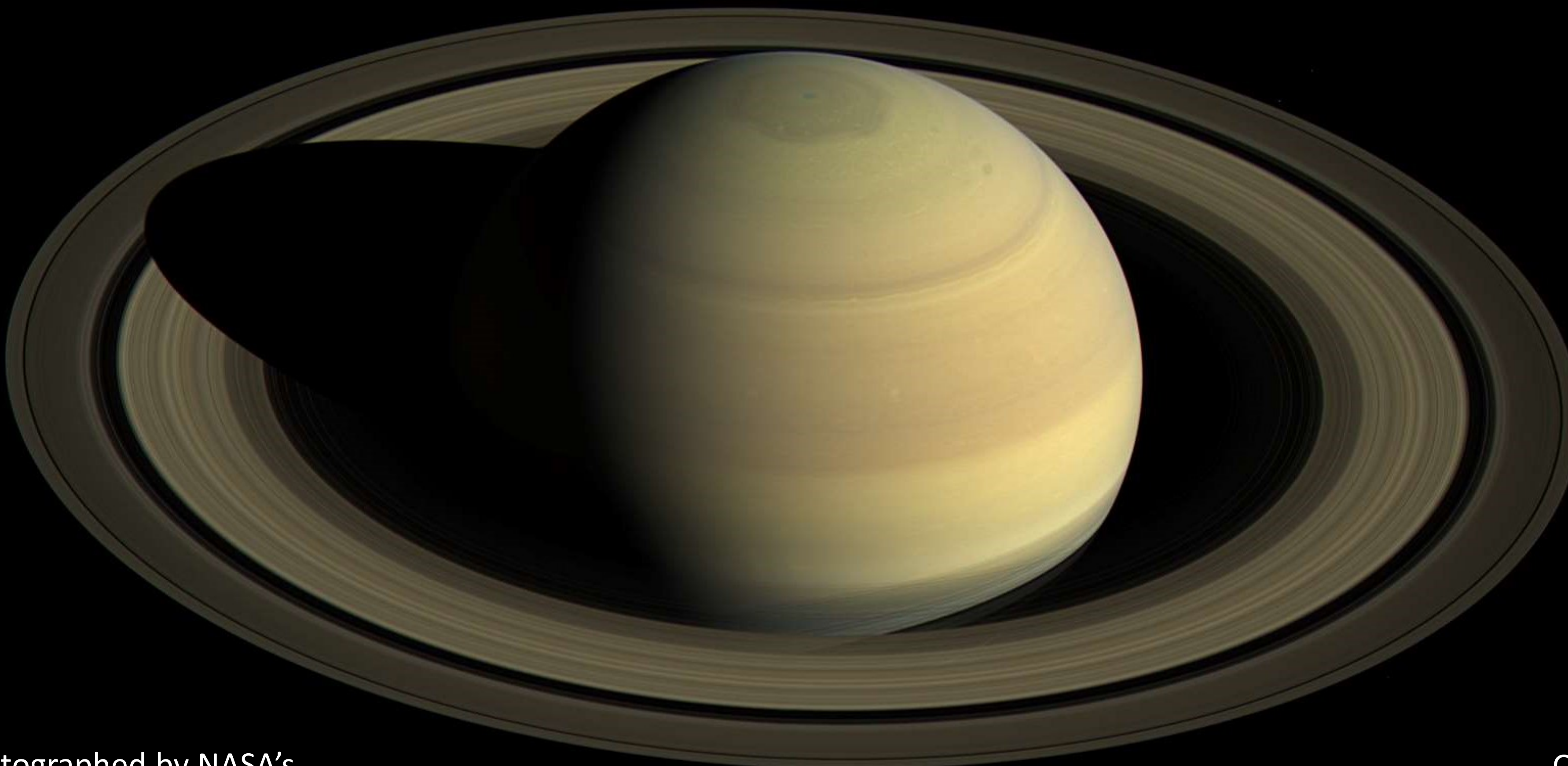
osmos to Chaos

A tour of cosmology through cultu
people and hist



n was photographed by NASA's
hi spacecraft on April 25, 2016

OLLI Spring
Andrew Jones,

Where Did We Leave the Greeks?

- Aristotle said the universe consisted of the seven crystalline spheres.
- The earth was fixed, and the sun, moon and stars rotated around it.
- The size of the universe was big – in terms of the day – but was limited to the locally observed heavens.
- There were four elements and they all had “natural” attributes and behaviors. The natural place of rocks was the center of the universe.
- The stars rotated around the earth in the most distant sphere. Some heavenly bodies occasionally “backed up” – called retrograde motion.
- This retrograde motion was explained by suggesting these (few) bodies were on sub-spheres which also rotated, called epicycles.

Where Did We Leave the Greeks?

- Aristotle agreed with earlier philosophers that said the heavens and all heavenly objects were made of *aether*, a transparent, misty substance.
- All objects moved in circles since that was a perfect geometric shape.
- The concept of atoms as the basis of mater was well established.
- The earth was a sphere – again a “perfect” shape. A flat, square, even an egg-shaped earth would have been esthetically unacceptable.
- So rocks fell, the sun rose and stars moved across the sky. Natural philosophy was all good everything made sense.

Eratosthenes

- Eratosthenes was a Greek scientist who followed Aristotle.
- He lived in Cyrene, Libya, from about 276 until 194 BC.
- He was the first person (known) to have actually measured the size of the spherical earth, which was assumed to be the case. He got pretty close.
- He knew that the sun illuminated the bottom of a well near Syene (now Aswan) in Egypt (south of Alexandria) on the summer solstice (June 21st on the Gregorian calendar.)
- The sun was then directly overhead on that day. The Tropic of Cancer.
- Aaahhh! Eratosthenes knew the distance from Syene to Alexandria was about 500 miles. He measured the angle of a shadow at Alexandria at roughly 7.2° or 1/50th of a full circle. So the circumference of the earth is then 50 X 500 or 25,000 miles. Correct! More or less.

Eratosthenes is also credited with inventing (developing? building?) the armillary sphere in the West. An armillary sphere is a model of objects in the sky or the celestial sphere, consisting of a spherical framework of rings, centered on the earth or the Sun. Other astronomically important features such as the ecliptic are often included.

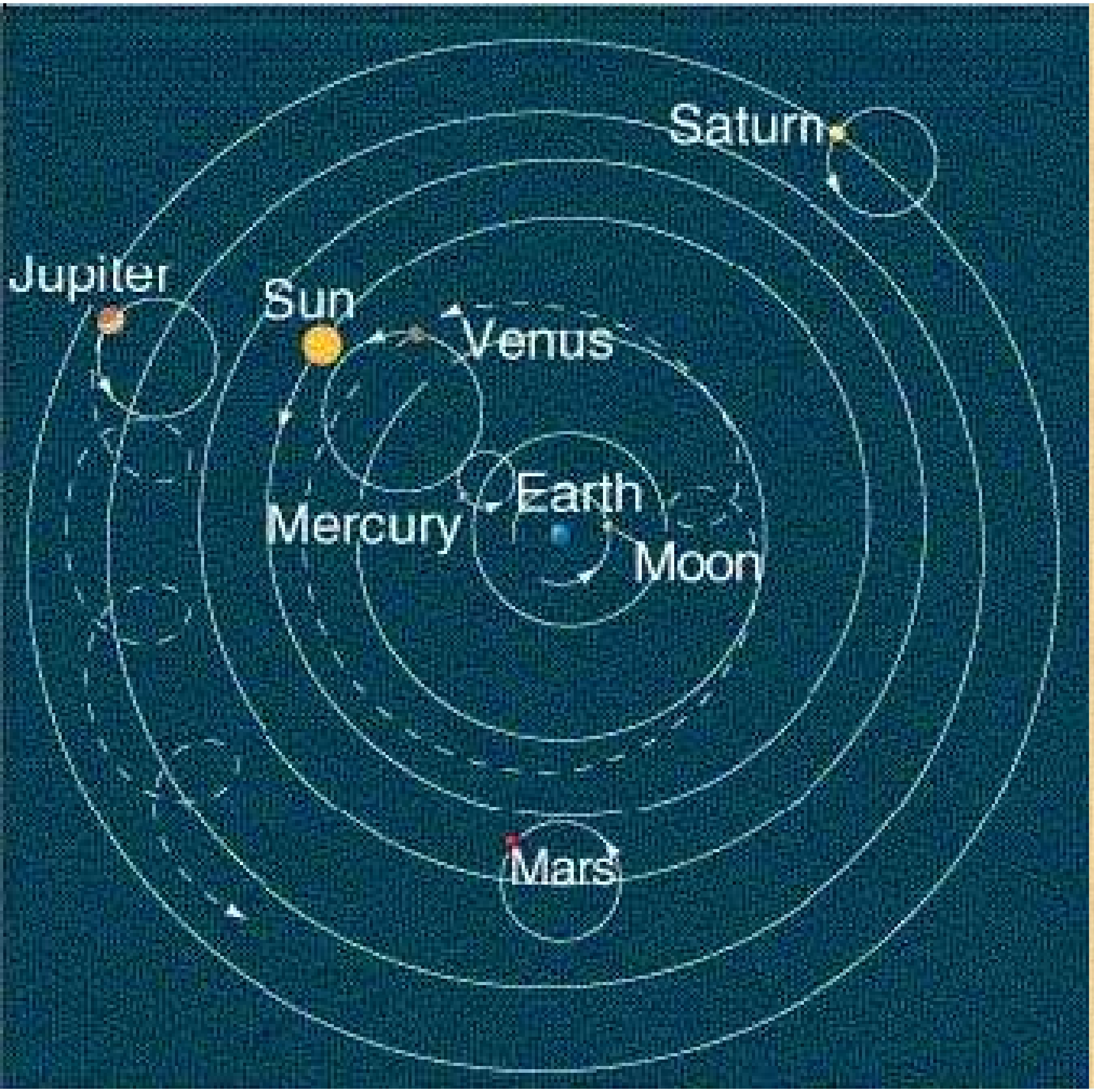
Claudius Ptolemaeus

- Ptolemy lived in the Greek province of Egypt from about 90 to 168 AD. He was of Greek decent and lived in the city of Alexandria.
- Ptolemy was quite the polymath (yes, a Greek word) and wrote on astronomy, math, geography, and harmonics (music).
- His book now known as the *Algamest* (this word is a hybrid of Arabic and Greek) sought to present empirical arguments for Aristotle's cosmology.
- He assumes that all the apparently irregular movements of the celestial bodies are still based on regular, uniform circular motion.
- Each planet is moved by two spheres: one is an epicycle. The other is its deferent (a circle who center is slightly off from the center of the earth.)
- The combination of these two spheres allowed Ptolemy to refine the older Greek system and better predict celestial motion.

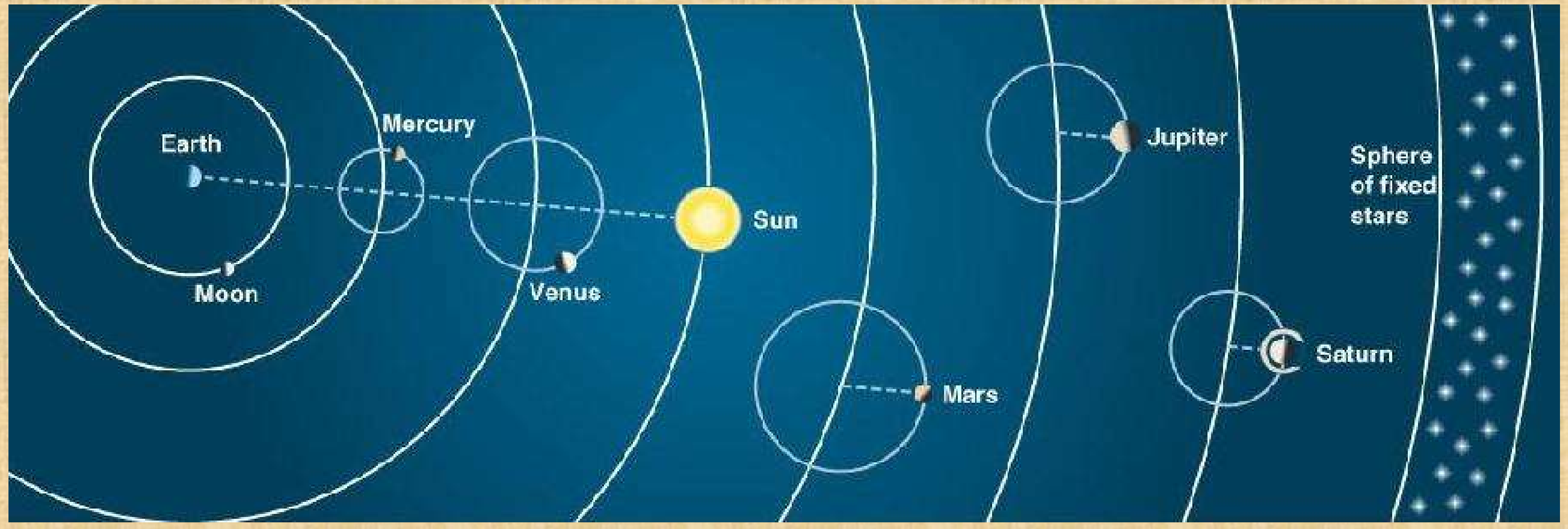
Until the 17th century, Ptolemy's version of Aristotle's cosmos was orthodox. This included a motionless earth surrounded by hollow concentric spheres in which were embedded the larger planets, the stars, and the sun. Beyond that was heaven. The moons of Jupiter sparked increased interest in the Greek manuscripts. Many of these documents were only preserved in monasteries and others were translated from the Arabic while the Moors controlled parts of Europe (from about 711 until 1492).

Ptolemy

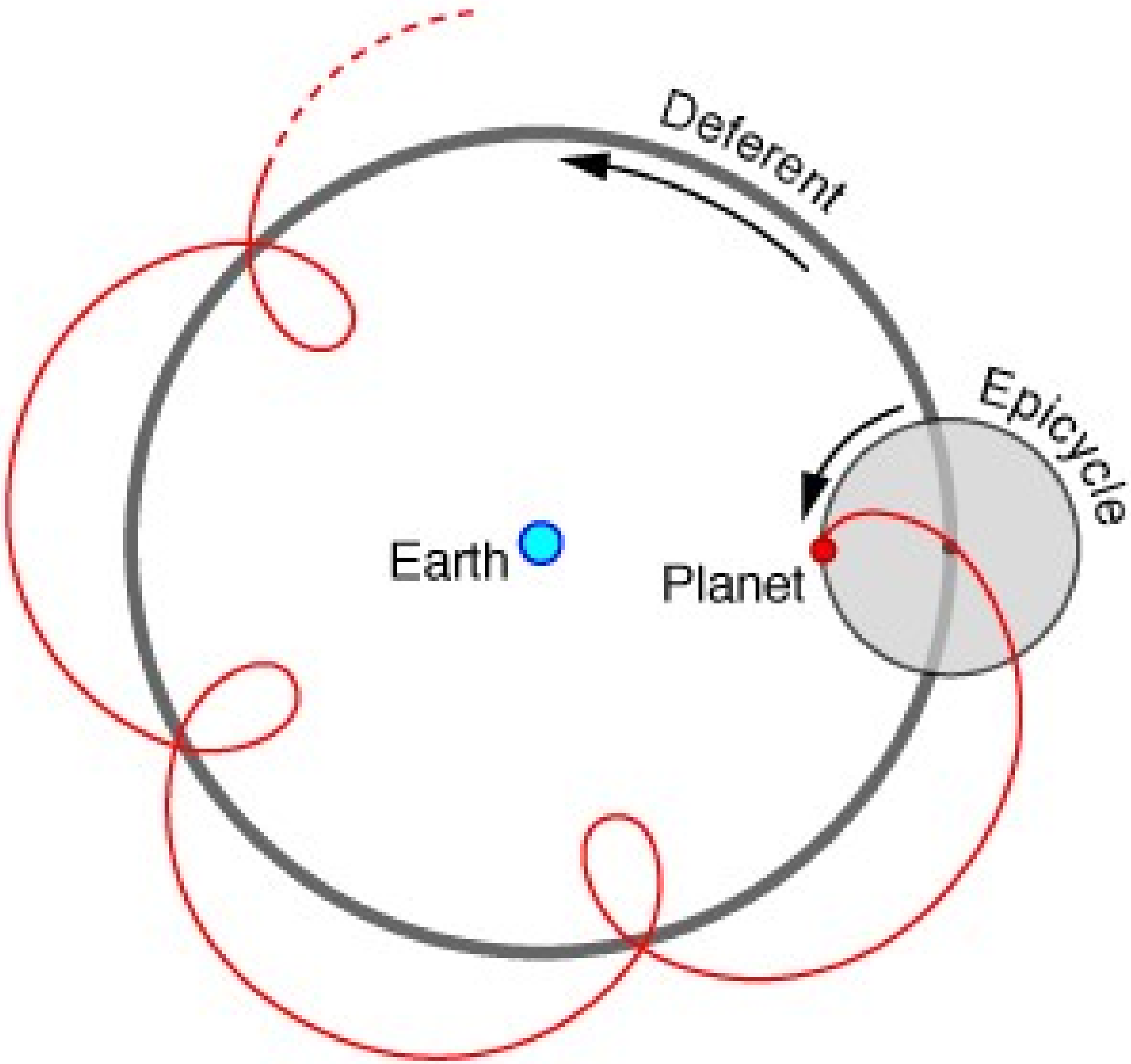
- His work (and Aristotle's) became the accepted cosmological theory by "science" and the Church for over a thousand years.
- Ptolemy was highly regarded in the Islamic world partly because of his work *Astrological Influences* which declared astrology to be legitimate and attempted to place astrology on a sound, "scientific" basis.
- This book described the physical effects of the position of the heavenly bodies on life on earth. He tried to reconcile the practice of astrology with the concepts of Aristotle.
- Ptolemy's works come to us through Arab references and recreations.



This modern sketch of Ptolemy's universe shows the seven spheres and which object resided there. The epicycles are shown for those objects that exhibit retrograde motion. The moon and the Sun do not require epicycles. The earth is stationary at the center.

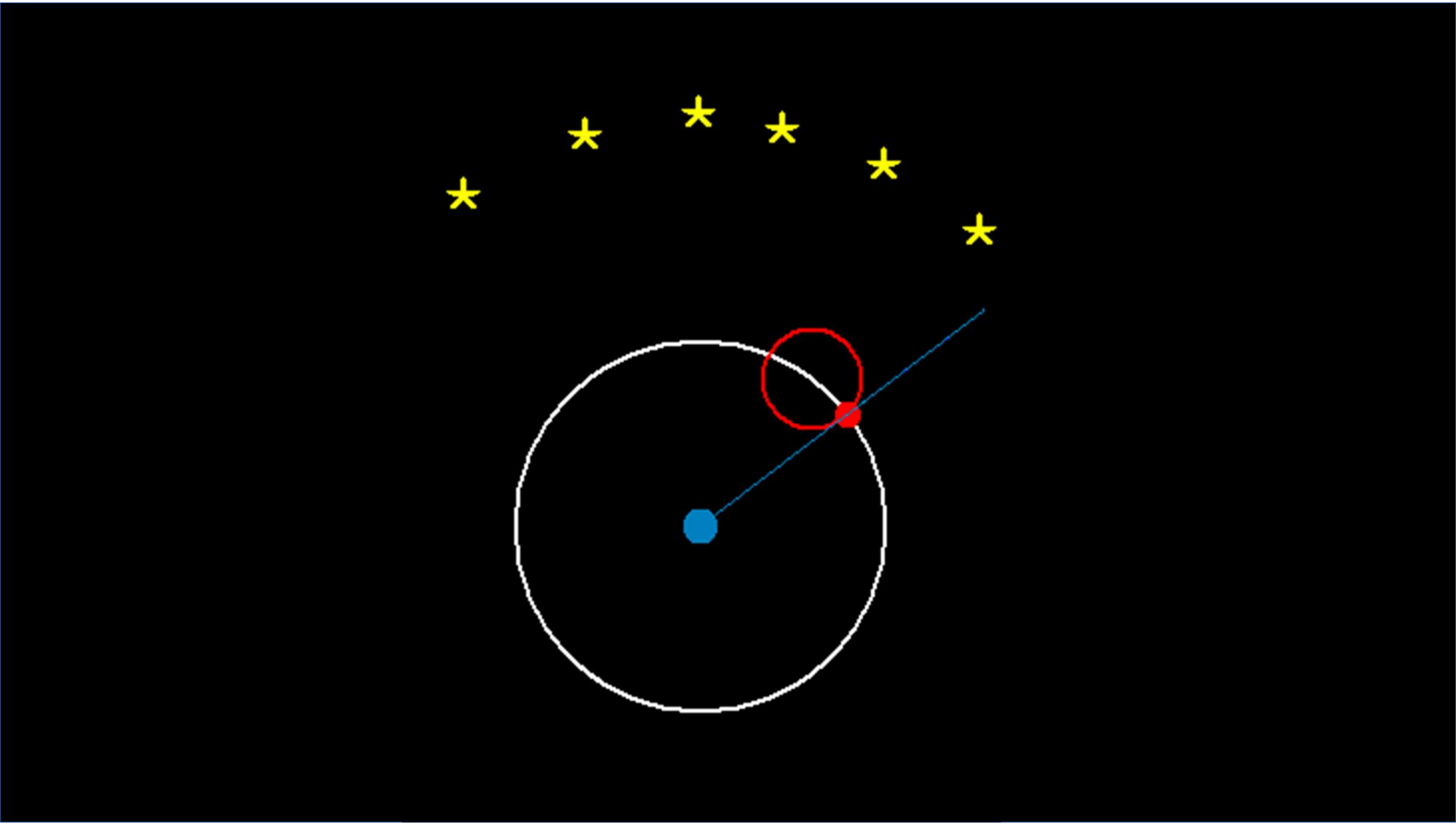


This is a close-up of the heavenly bodies and their epicycles. Note the sphere of fixed stars outside the orbit of Saturn. The size of the orbits and the size of the epicycles are not to scale.



Epicycles

"Planet" comes from the Greek word for "wander" and these objects were called planets since they "wandered" in the heavens – they occasionally moved in the wrong direction! Adding epicycles to the basic orbits of these planets was a stroke of genius and not bad "science". It was a pretty good attempt at modifying theory to better match observation. It would be 1800 years before Kepler used ellipses instead of circles to get better results than the Greeks got with epicycles.



Greek Cosmology

- Recall that the Greeks did very few experiments and so two principles informed the Greek view of the world and the universe we live in.
- The first was perfection. If it was in the realm of the gods, it had to be perfect. And there was no possibility of corruption or decay.
- The second was order. Nature provided an orderly universe and this was one of the reasons experiments were not needed. Disorder was imperfection.
- When it was all thought out, the heavens were perfect and perfectly ordered.

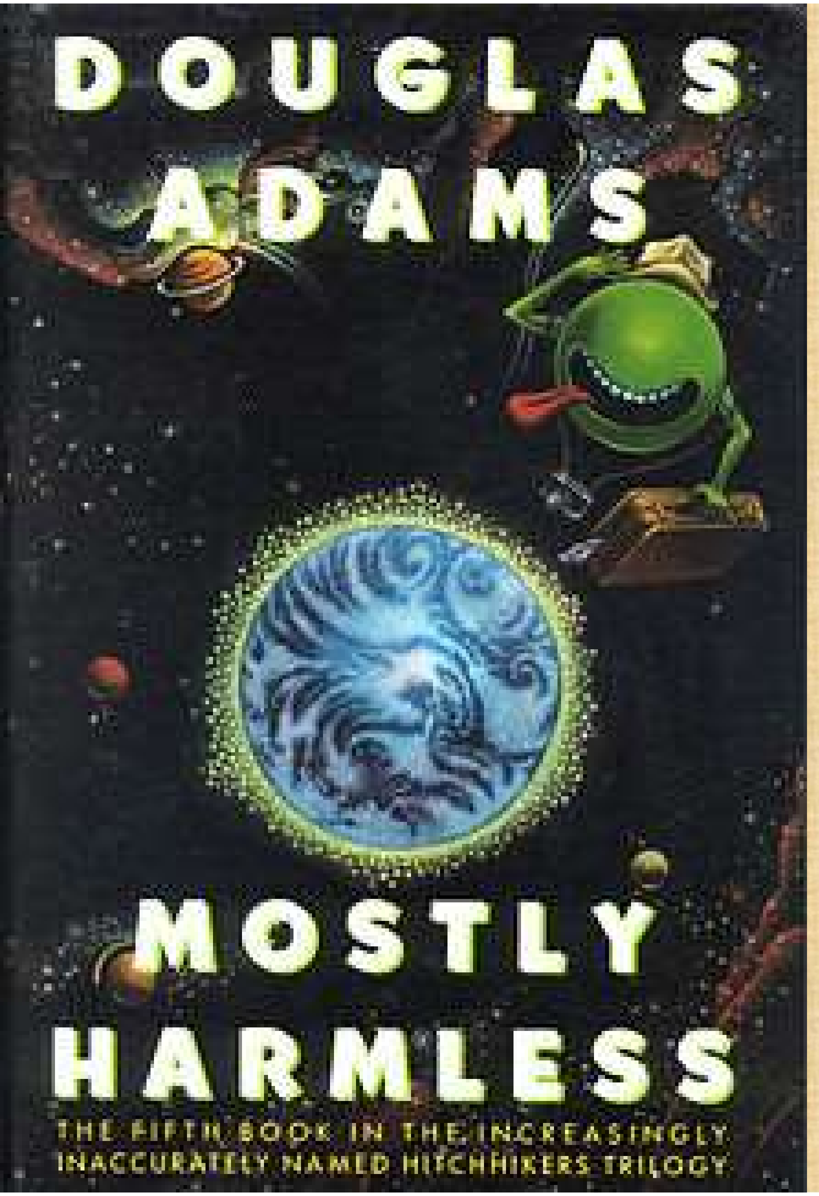
Now fast forward to the modern era.
And an alternate view of cosmology.

With Apologies to Douglas Adams

- Douglas Adams wrote the *Hitchhiker's Guide to the Galaxy* in 1978.
- The *Guide* was supposed to serve as "the standard repository for all knowledge and wisdom" about the universe.
- The *Guide* began as part of Adam's BBC radio show, became a book, then a (not very good) movie, a TV series, video games and several other incarnations.
- The *Guide* was known for typos, inaccuracies, and dangerously incorrect information.
- Adams wrote of the *Guide* "where it is inaccurate, it is at least *definitively* inaccurate. In cases of major discrepancy, it was always reality that's got it wrong."
- There are five books in the *Hitchhiker Trilogy*. They are really good.

Douglas Adams Novels

• Hitchhiker’s Guide to the Galaxy	1978
• The Restaurant at the End of the Universe	1980
• Life, the Universe and Everything	1982
• So long, and Thanks for All the Fish	1984
❖ Dirk Gently’s Holistic Detective Agency	1987
❖ The Long Dark Tea-Time of the Soul	1988
• Mostly Harmless	1992



The fifth book in the trilogy?

Is the universe less interesting, less like fantasy, than a Douglas Adams book?

Let’s explore life, the universe and everything. Not necessarily in that order. We will start with scale – the size of things.

Scale

- It is hard to get your head around the scale of the universe.
- Everyday experience leads us think we understand it.
- The scale - the perceived size and age of the universe – have been increasing over the entire recorded history of humans.
- The Greeks assumed the universe was big but the fact that they could not observe relative movement in the stars – parallax due to observing stars in the summer and winter – lead them to assume the stars were "fixed."
- It was inconceivable that the stars were so distant that they did not exhibit this parallax.
- Time was ignored since it was assumed that everything had existed forever.

How Big IS the Universe?

- The Universe is BIG. So big we can not reasonably characterize it in distance units. We have to use time. Don’t worry if you can’t get your head around it.
- Light travels at a rate of about 300 x 10^6 meters per second or 186 x 10^3 miles per second.
- This means light travels about 671 x 10^6 (67 million) miles per hour.
- A light year is 5978 billion miles (or 5978 x 10^9). That is further than California.
- This means the light from the sun takes about 8 minutes to travel the 93 million miles between the sun and earth.
- The most distant galaxies we can observe with the Hubble Telescope are about 13 billion light years away. Or about 13 billion years old.

Relative Scale of the Earth, Moon and Sun?

Let’s Compare the sizes of the Earth, Sun, Moon, and the distances between them.

Relative Scale of the Earth, Moon and Sun?

- The moon is about 1/4th the size of the earth. It averages about 240,000 miles from the earth (which Is 30 earth diameters).
- The sun is about 108 times the size of the earth.
- If the sun were one foot across, the earth would be a BB or less than 0.10 inch across. The moon could not be seen in this example. (I could not find an object that was .025 inches across.
- On this scale the earth (the BB) would be about 108 feet away from the sun. Feeling insignificant? Hang on, it gets worse.

Local Astro-Scales

- The earth is about 0.043 of a light-second across (43 milliseconds.) The moon is a bit less than 1.3 light-seconds away from earth.
- The sun is about 8.3 light-minutes away from earth.
- The nearest star to earth (except the sun) is Proxima Centauri (in the Alpha Centauri group in the Milky Way) and is 4.2 light-years away.
- The center of the Milky Way galaxy is between 25,000 and 28,000 (25 x $10^{3)}$ light-years from the earth.
- The Andromeda Galaxy – the one closest to our Milky Way – is over 2.5 million light-years away (2.5 x 10^6 light-years.) More exponents?

Astro-Glossary

- **Star** – a star is a ball of gas, mainly hydrogen, which is so large that the internal gravitational forces are strong enough that nuclear fusion occurs. Not an atomic bomb, but fusion, called a hydrogen bomb.
- **Solar System** – a group of planets orbiting a central star. We have directly identified almost 4,000 solar systems with planets in our galaxy. These planets are often called "exoplanets."
- **Galaxy** – a galaxy is a collection of stars held together by gravity. The Milky Way is a typical galaxy, and it contains over 100 billion stars. There are currently over 100 billion galaxies visible to us on earth.
- **Nebula** – an old name for fuzzy celestial objects before it became obvious that they were whole galaxies.
- **Cluster** – a group of galaxies held together by their mutual gravity.

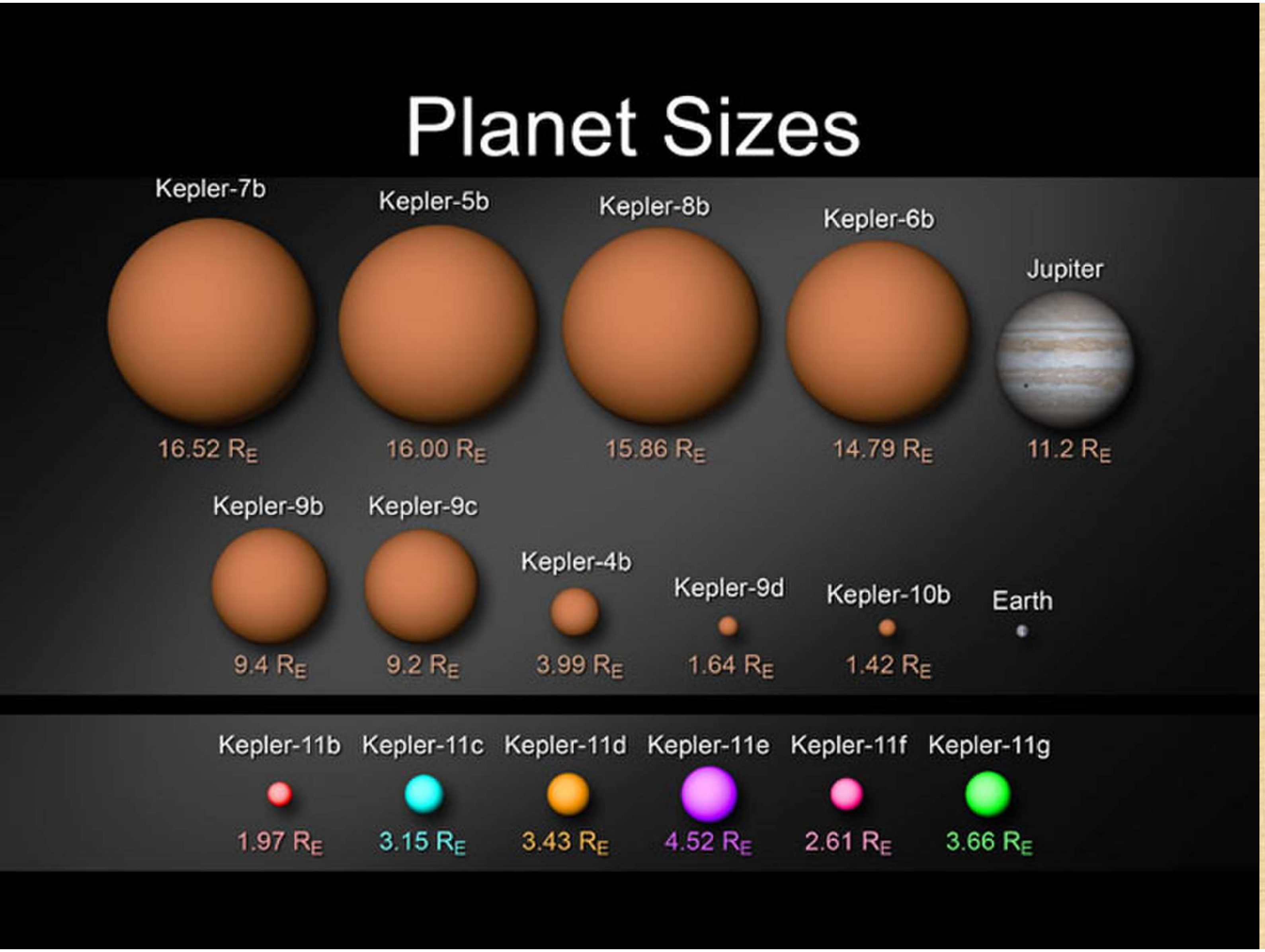
The USS Gerald R. Ford (CVN 78) is over 1,100 feet long and has a crew of 2,600 sailors and Marines. The supercarrier displaces 100,000 tons and carries about 60 F35 jets. It employees two nuclear reactors for the engines and electrical energy to power the catapults and the ship.

Other Solar Systems in the Milky Way

- Can we detect other solar systems or exoplanets? At least three ways:
- We can look for the “wobble” of a central star due to the gravity of orbiting planets. This limits the search to very large planets, but new instrumentation has increased the accuracy of this technique.
- We can look at the (partial) eclipse as the planet passes in front of the star. The apparent luminosity of the star decreases as the planet passes in front of it.
- We can actually look at the infrared profile of a planet using some new spectrometers which have been developed in the past few years. They are extremely sensitive and accurate.

Other Solar Systems in the Milky Way

- Most exoplanets were discovered by satellite-based telescopes – many by the now ended Kepler mission.
- These techniques can only discover planets with very special characteristics – planets that pass between the star and the earth, for example. Thus, we only find a small subset of the existing planets. Do all, or at least most, stars have planets? Many astronomers say yes.
- Most astronomers estimate that there are probably several 100 billion exoplanets in the Milky Way that are in the Little Red Riding Hood zone of their star.



This chart compares several confirmed exoplanet sizes to Jupiter and the earth. Of course, the larger the planet, the easier it is to find, independent of the technique used! This biases the results of a search to larger planets.

NASA/Tim Pyle

Legacy of Aristotle

- The basic view of the universe that was published by Aristotle and then Ptolemy was incorporated into the doctrine of the Church.
- During the long period between the collapse of Rome and the rise of the Renaissance (roughly between 476 and 1350 AD) few people dared to challenge the Church on matters religious, civil, or scientific.
- As new ideas were explored in the early Renaissance, there was extensive conflict with the Church.
- Nicolaus Copernicus was not the only or the first to question Ptolemy's description of the solar system. But his book was comprehensive.
- Copernicus waited until he was on his deathbed (in 1543) before allowing his book describing the heliocentric solar system to be printed.

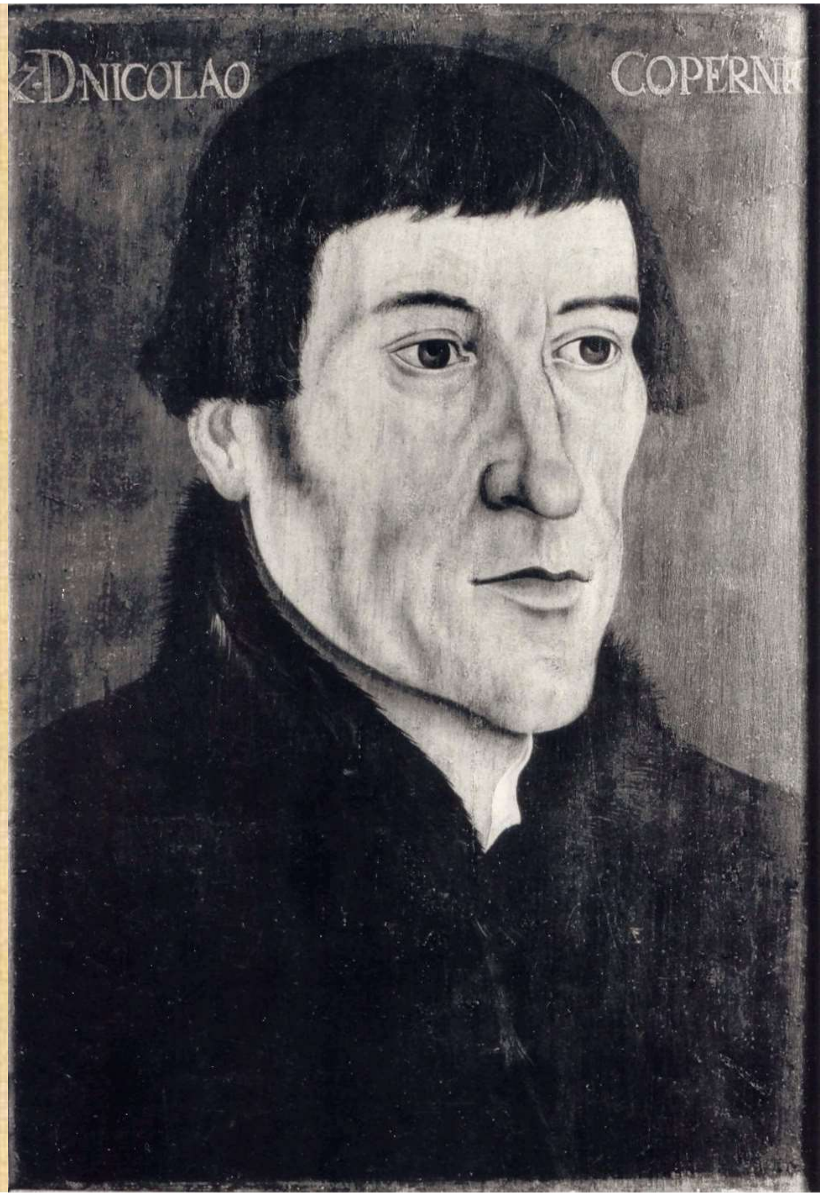
Copernicus – The First Revolution

- Copernicus' basic idea was that the earth orbited the sun. This concept already had many adherents but it was not proven and was contrary to Church doctrine. No one had laid out a logical, comprehensive argument.
- The Vatican had a sophisticated college of scientists and astronomers who were providing serious observations to the science community.
- Copernicus also concluded that all the other planets orbited the sun.
- But he kept Aristotle's perfect circles. This meant that his model actually produced ***less accurate*** results than Ptolemy and his epicycles.
- Copernicus' apologists defended their position by saying that this was simply a model; it did not necessarily represent physical reality. The Church did not buy that argument from Galileo either.
- The basic objection to this model was that it displaced the earth from its special position in the universe.

Nicolaus Copernicus

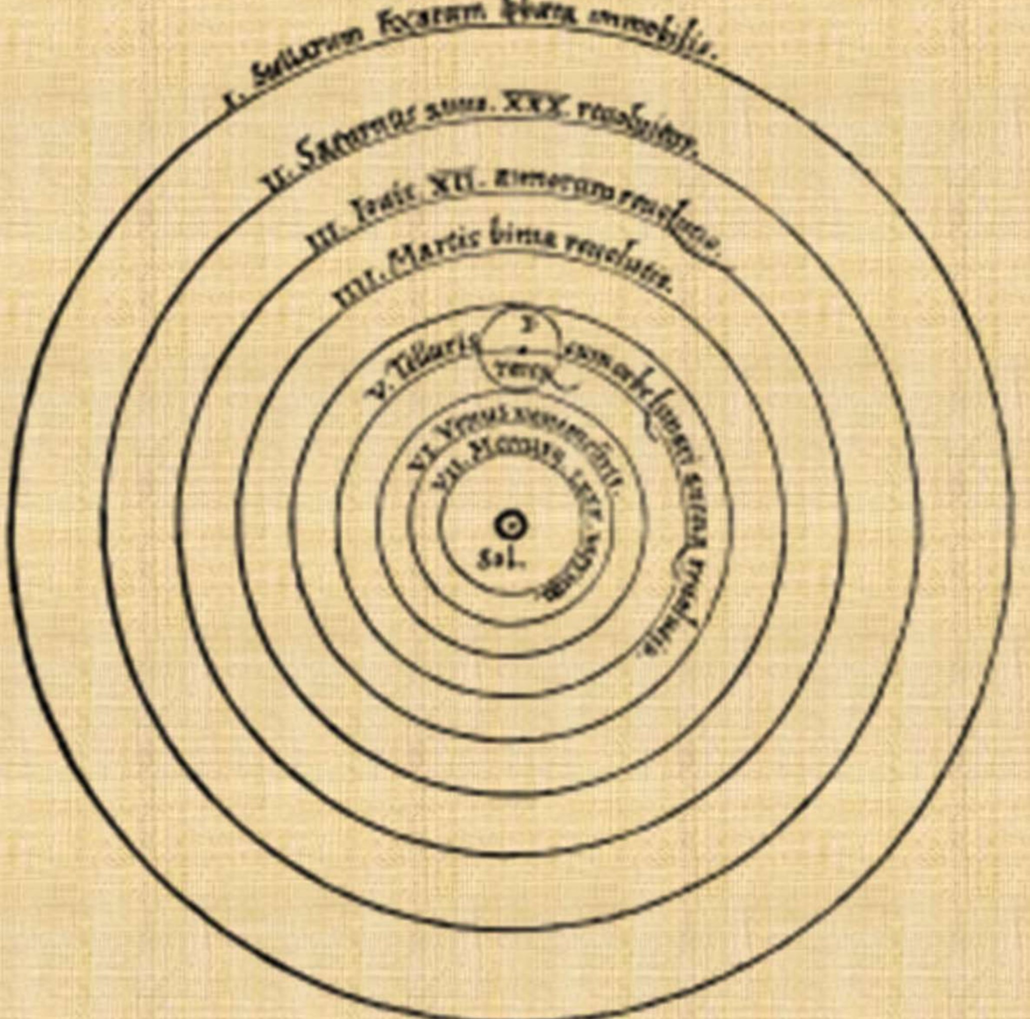
This is a 16th-century portrait of Copernicus. The original painting is lost, probably looted by the Germans during WWII when they occupied Poland. It has surely been destroyed.

Copernicus was appointed a secular canon of the Warmia diocese by his uncle, who he also served as secretary and physician. He was greatly conflicted by his astronomical observations and studies and only agreed to have his book published under pressure from Georg Joachim Rheticus, who came to study astronomy under Copernicus, and was a cohort of Philip Melanchthon and Martin Luther. He is shown here as a young man although he was 70 when he died, and his book was published.



Copernicus’ Revolution

- Many European scientists (allowing for a bit of poetic license) greeted this book with a yawn. “Yes, we all sort of expected someone to say that, sooner rather than later.”
- The problem was that the obvious logic behind the book threatened the authority of the Church. A simple Papal Bull could no longer settle questions of science.
- The Church was under attack from many quarters. The Inquisition had been in place since the 12 century but had become less effective in quelling independent thought and ideas contrary to asserted doctrine.



An illustration from the orignial book published by Copurnius at his death.
Dē revolutionibus orbium coelestium
(*On the Revolutions of the Celestial Spheres*)

Copernicus’ Revolution

- This period of the Renaissance was very tumultuous. In addition to Copernicus, paintings of humans, Mary and the Christ Child, for example, begin to show actual physical attributes – beginning with Albrecht Dürer in about 1500.
- Columbus challenged the basic assumptions of geography. He was wrong, of course. India did NOT reside just over the horizon. He died believing it did and that he had found it! Even after he came to the New World ***three*** times.
- Luther directly challenged the authority of the Pope. Again, he was not the only or the first but had had powerful friends to shield him from the Pope and the Church hierarchy.
- Even music was controversial. This is when hymns were beginning to be sung in church. Luther wrote a bunch.

Tycho Brahe

- Brahe was the best observer of the heavens, and recorder of his observations, during the Renaissance.
- While a student in 1566 Tycho lost part of his nose in a sword duel with his cousin. He was fitted with a brass prosthesis.
- Brahe was the last of the “naked eye” astronomers, working without a telescope.
- He developed new instruments and techniques to measure celestial motion.
- His first assistant was his younger sister, Sophie.

Tycho Brahe

This painting shows Brahe as a 32-year-old aristocrat in 1578. He is wearing his Order of the Elephant medal, as a Danish Knight.

Tycho has his brass nose at this age, but the artist was wise enough not to emphasize it. Almost all portraits of Brahe show him with an opulent mustache. Perhaps that was his attempt to divert attention from his prosthesis.

Tycho Brahe

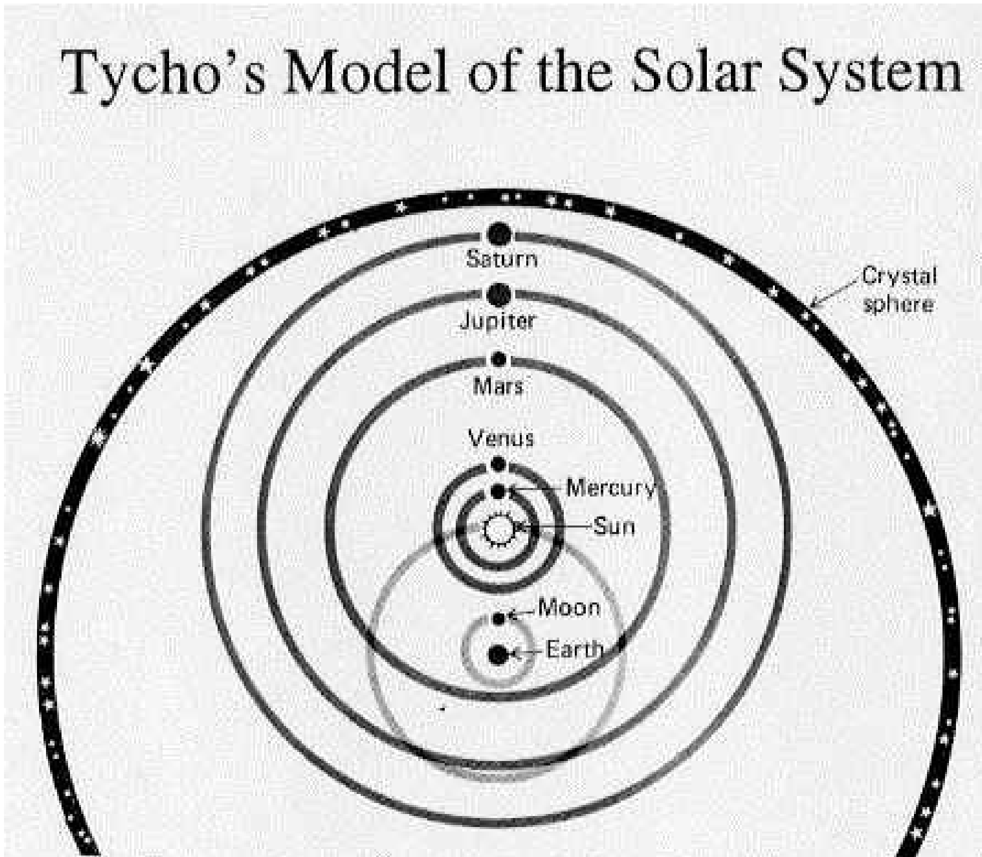
This woodcut shows Tycho as a bit older and his brass nose is more pronounced.

Tycho Brahe

- Brahe declined an offer of a castle from his King and so instead the King gave him an island for his observatory.
- Tycho was also appointed to be a canon of a Cathedral, giving him lifetime support.
- Tycho fell in love with a commoner and engaged in a morganatic marriage.

Tycho Brahe

- By the 1570's Brahe was still trying to show that the sun did, in fact, orbit the earth.
- His measurements showed that the earth-centered model could work just as well, or better, than Copernicus' sun-centered model.
- But he disagreed with Aristotle about the immutability of the celestial spheres and showed that comets come from outside our atmosphere.
- Tycho died in his prime, at 54, in Prague of a burst bladder after a drinking bout.



Tycho could not accept Copernicus' heliocentric model of the solar system. His observations allowed him to develop a composite model which "saved" the geocentric earth. It worked about as well as Copernicus and much better than the geocentric model of Aristotle.

Galileo Galilei

- It is not clear that Copernicus and his writings lead directly to Galileo discoveries and writings. But they might have.
- Galileo was familiar with Copernicus' work and announced his agreement with his basic theories.
- Galileo was consumed with challenging <u>everything</u>.
- He believed that mathematics could provide answers to some vexing questions and that controlled observations (experiments) were the only way to learn nature's rules.
- His treatises on mechanics (motion, friction, forces, etc.) were very advanced and lead Newton, and Liebniz, a German mathematician, to develop the calculus.

Galileo Galilei

This is the famous portrait of Galileo painted by Justus Sustermans in 1636 when Galileo was 70 years old. By this time he had been convicted of heresy and sentenced to "house arrest." His daughter Virginia (as Sister Maria Celeste) took care of him. He was also essentially blind. He died seven years later.

Sister Maria Celeste

Galileo’s eldest child was named Virginia but her illegitimate birth meant she could not marry (well). Galileo persuaded a local order – the convent of San Matteo to accept both his daughters. He had to support them with regular contributions to the convent. After years of turmoil, his son Vincenzio, his youngest child, was eventually “legitimized”, recognized as Galileo’s heir, and married.

Galileo Galilei

- Galileo studied medicine at the University of Pisa and later was appointed to a mathematics Chair. Later he assumed a similar role at the University of Padua, although he lectured on many subjects.
- His lectures were so popular a new hall in Padua was built to accommodate the crowds. The building is still there
- His career as a scientist was piqued by watching a chandelier swinging and concluded that the period of a pendulum is independent of the amplitude of its motion. A hundred years later Huygens published a formal theory of the pendulum and thereafter accurate clocks appeared.
- He was prolific in developing and patenting inventions. This was probably done to help mitigate his financial obligations.

Galileo Galilei

- Galileo made his mark with Cosmo II, Grand Duke of Tuscany because of his calculations that improved the accuracy of the trajectory of ballistic canon balls.
- He built his own telescope based on a description provided by Hans Lippershey, the German-Dutch spectacle maker who invented the refracting telescope. Galileo made improvements to the design.
- Galileo almost immediately discovered the moons of Jupiter. He understood the significance of this observation: it refuted Aristotle's base assumptions about the universe.
- The Vatican astronomers scoffed at Galileo, suggesting the observed moons were simply dirt on the lenses or imperfections in the glass.

Galileo Galilei

- Galileo thought that careful observations of the Jovian moons would allow him to more accurately forecast the tides, perhaps even determine longitude. This would be a huge military advantage. The Duke made him court mathematician.
- Galileo persisted with his observations and continued to insist that Copernicus was right, that the earth moved in orbit around the sun.
- The Pope demanded Galileo to refute Copernicus in 1616 and not teach heliocentric theory.
- Also in 1616, Copernicus' book was finally – after 100 years – placed on the Inquisition's Index (of banned books).
- Galileo wrote his *Dialogue Concerning the Two Chief World Systems,* dedicated it to Pope Urban VIII, and submitted it to the Church censors. It was approved and was published.

Galileo Galilei

- Someone in the Vatican finally read the book as opposed to the Dedication. They were not amused.
- One protagonist in the book was obviously modeled on Galileo and he argued that Copernicus was right and used logic and all the observations of Galileo to justify his position.
- On the other side of the debate, the character was confused and often used conflicting arguments. He was clearly modeled after the Pope (or his astronomers.) His name was Simplicio. Yep. Simpleton.
- In 1633 Galileo was told to report to the Vatican for a trial by the Inquisition.
- He tried to minimize his differences with the Church, but he was “convicted” of heresy and prohibited from teaching or writing about the heliocentric theory. He was also given house arrest for life. This is when legend has it that he uttered the famous statement “And yet it moves.”

The Doge of Venice and Galileo’s Telescope

Galileo was asked to show many important people his telescope. It was a curiosity that was astounding to most people. Some important people refused to believe what they were seeing even after seeing it. Most assumed that Galileo used some sort of gimmick or deception to fool viewers. Galileo built telescopes for a number of these people.

Galileo Galilei

- His book was placed on the Index of prohibited works, joining Copernicus'.
- Only five years later in 1638, the book was republished – away from Rome – and widely distributed.
- While under house arrest, Galileo wrote a book called *The Two New Sciences*. It was based on work he did 40 years earlier and dealt with kinematics and strength of materials.
- That book was spirited out to Holland – which was a thorn in the Church's side in many ways – and published there, avoiding the censors in Rome.
- When Galileo died in 1642 the Grand Duke of Tuscany wanted to build a monument to him and bury him with the royal family. The Pope and one of Galileo's main nemeses, Cardinal Barberini, intervened and he was interred in a simple grave. Later his remains were moved to a more prominent place with a monument.

Galileo Galilei

- Galileo maintained his innocence to the end, claiming he was a loyal Catholic. He never understood the conflict between his scientific conclusions and the doctrine of the Church.
- “The Bible shows the way to go to heaven, not the way the heavens go.”
- The Church finally abrogated its finding of heresy in 1992. “It moves.”
- This was the result of a 13 year – 13 year! – investigation.
- There is a strong case that the heliocentric theory was merely the pretext for trying to silence Galileo.
- The Church, battered by the assaults of the 15^{th} and 16^{th} centuries, clung to a single remaining divine act – offering the Eucharist where the wine was changed into the Blood, and the bread into the Body of Christ.
- Galileo had supported the theory of atoms (first proposed by Leucippus and expanded by Democritus) which threatened this last stronghold.

Post Galileo

Galileo laid the foundation for the scientific revolution that followed him in the 18th and 19th centuries. His heirs include:

- Kepler – Galileo was a contemporary, but his endorsement of Kepler's work was a major boost for that theory.
- Isaac Newton – 1642 to 1727 (in the Gregorian calendar.) He is not usually called an astronomer but had a major influence on astronomy through his theory of attraction and his equation for gravity.
- James Clerk Maxwell – 1831 to 1879. His theory and equations of electricity and magnetism formed the basis for Einstein's General Theory.
- Hendrik Lorenz – 1853 – 1928. He was the mathematician who gave Einstein the basic concepts for his Special Relativity.

Galileo’s Legacy

- Galileo discovered comets, stars, moons, the force of gravity, characteristics of ballistic objects, sunspots, the Milky Way (as stars rather than as a diffuse ”nebula”), invented the compound microscope, improved compasses and thermometers.
- And, yes, he returned to the thing that seduced him into science initially: toward the end of his life, while mostly blind, he developed an escapement which allowed the use of a pendulum in a clock.
- Consider his broad scientific shoulders ready for Newton.

Galileo’s Clock

Galileo designed this clock about 1642 while he was confined to his house and mostly blind. It was based on the principle that the period of a pendulum is almost independent of the amplitude of the arc (for small arcs), the very observation that brought him into science in the first place. He died before he could develop an escapement or finish building it. His son Vincenzio helped. The first pendulum clock was finally built by Huygens in 1656.