History of Astronomy

Covers the history of astronomy from the ancient Greeks through the Big Bang.

- Identify major occurrences in the history of astrophysics and identify the individuals who make the contribution.



[Figure1]

This is a classic spiral galaxy known as the Whirlpool Galaxy. It is found in the Canes Venatici constellation. This constellation represents the hunting dogs, Asterion and Chara.

The History of Astronomy

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Astronomy and the Ancient Greeks

The Astronomy of the ancient Greeks was linked to mathematics, and Greek astronomers sought to create geometrical models that could imitate the appearance of celestial motions. This tradition originated around the 6th century BCE, with the followers of the mathematician Pythagoras (~580 – 500 BCE). Pythagoras believed that everything was related to mathematics and that through mathematics everything could be predicted and measured in rhythmic patterns or cycles. He placed astronomy as one of the four mathematical arts, the others being arithmetic, geometry and music.

While best known for the Pythagorean Theorem, Pythagoras did have some input into astronomy. By the time of Pythagoras, the five planets visible to the naked eye - Mercury, Venus, Mars, Jupiter and Saturn - had long been identified. The names of these planets were initially derived from Greek mythology before being given the equivalent Roman mythological names, which are the ones we still use today. The word 'planet' is a Greek term meaning 'wanderer', as these bodies move across the sky at different speeds from the stars, which appear fixed in the same positions relative to each other.

For part of the year Venus appears in the eastern sky as an early morning object before disappearing and reappearing a few weeks later in the evening western sky. Early Greek astronomers thought this was two different bodies and assigned the names 'Phosphorus' and 'Hesperus' to the morning and evening apparitions respectively. Pythagoras is given credit for being the first to realize that these two bodies were in fact the same planet, a notion he arrived at through observation and geometrical calculations.

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Pythagoras was also one of the first to think that the Earth was round, a theory that was finally proved around 330 BCE by Aristotle. (Although, as you are probably aware, many people in 1642 CE still believed the earth to be flat.)

Aristotle (384 BCE – 322 BCE) demonstrates in his writings that he knew we see the moon by the light of the sun, how the phases of the moon occur, and understood how eclipses work. He also knew that the earth was a sphere. Philosophically, he argued that each part of the earth is trying to be pulled to the center of the earth, and so the earth would naturally take on a spherical shape. He then pointed out observations that support the idea of a spherical earth. First, the shadow of the earth on the moon during a lunar eclipse is always circular. The only shape that always casts a circular shadow is a sphere. Second, as one traveles more north or south, the positions of the stars in the sky change. There are constellations visible in the north that one cannot see in the south and vice versa. He related this to the curvature of the earth. Aristotle talked about the work of earlier Greeks, who had developed an earth centered model of the planets. In these models, the center of the earth is the center of all the other motions. While it is not sure if the earlier Greeks actually thought the planets moved in circles, it is clear that Aristotle did.

Aristotle rejected a moving earth for two reasons. Most importantly he didn't understand inertia. To Aristotle, the natural state for an object was to be at rest. He believed that it takes a force in order for an object to move. Using Aristotle's ideas, if the earth were moving through space, if you tripped, you would not be in contact with the earth, and so would get left behind in space. Since this obviously does not happen, the earth must not move. This misunderstanding of inertia confused scientists until the time of Galileo. A second, but not as important, reason Aristotle rejected a moving earth is that he recognized that if the earth moved and rotated around the sun, there would be an observable parallax of the stars. One cannot see stellar parallax with the

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naked-eye, so Aristotle concluded that the earth must be at rest. (The stars are so far away, that one needs a good telescope to measure stellar parallax, which was first measured in 1838.)

Aristotle believed that the objects in the heavens are perfect and unchanging. Since he believed that the only eternal motion is circular with a constant speed, the motions of the planets must be circular. This came to be called "The Principal of Uniform Circular Motion." Aristotle and his ideas became very important because they became incorporated into the Catholic Church's theology in the twelfth century by Thomas Aquinas. In the early 16th century, the Church banned new interpretations of scripture and this included a ban on ideas of a moving earth.

Claudius Ptolemy (90 – 168 CE) was a citizen of Egypt which was under Roman rule during Ptolemy's lifetime. During his lifetime he was a mathematician, astronomer, and geographer. His theories dominated the world's understanding of astronomy for over a thousand years.

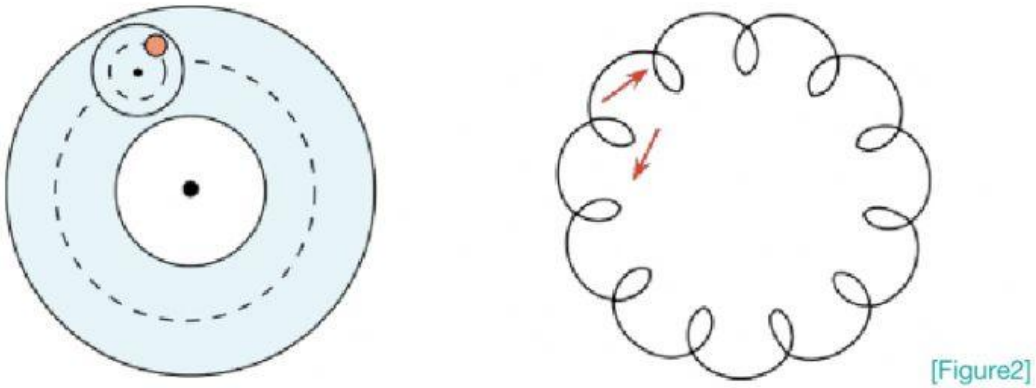
While it is known that many astronomers published works during this time, only Ptolemy's work *The Almagest* survived. In it, he outlined his geometrical reasoning for a geocentric view of the Universe. As outlined in the Almagest, the Universe according to Ptolemy was based on five main points: 1) the celestial realm is spherical, 2) the celestial realm moves in a circle, 3) the earth is a sphere, 4) the celestial realm orbit is a circle centered on the earth, and 5) earth does not move. Ptolemy also identified eight circular orbits surrounding earth where the other planets existed. In order, they were the moon, Mercury, Venus, the Sun, Mars, Jupiter, Saturn, and the sphere of fixed stars.

A serious problem with the earth-centered system was the fact that at certain times in their orbits, some of the planets appeared to move in the opposite direction of their normal movement. This reverse direction movement is referred to as "**retrograde**

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motion." If the earth was to remain motionless at the center of the system, some very intricate designs were necessary to explain the movement of the retrograde planets.

In the Ptolemaic system, each retrograde planet moved by two spheres.



[Figure2]

The Ptolemaic system had circles within circles that produced **epicycles**. In the sketch above on the left, the red ball moved clockwise in its little circle while the entire orbit also orbited clockwise around the big circle. This process produced a path like that shown in the sketch above on the right. As the red ball moved around its path, at some times it would be moving clockwise and then for a short period, it would move counterclockwise. This motion was able to explain the retrograde motion noted for some planets.

Astronomy and the Late Middle Ages

It was not until 1543, when Copernicus (1473 – 1543) introduced a sun-centered design (**heliocentric**), that Ptolemy's astronomy was seriously questioned and eventually overthrown.

Copernicus studied at the University of Bologna, where he lived in the same house as the principal astronomer there. Copernicus assisted the astronomer in some of his observations and in the production of the annual astrological forecasts for the city. It is at Bologna that he probably first encountered a translation of Ptolemy's *Almagest* that

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would later make it possible for Copernicus to successfully refute the ancient astronomer.

Later, at the University of Padua, Copernicus studied medicine, which was closely associated with astrology at that time due to the belief that the stars influenced the dispositions of the body. Returning to Poland, Copernicus secured a teaching post at Wroclaw, where he primarily worked as a medical doctor and manager of Church affairs. In his spare time, he studied the stars and the planets (decades before the telescope was invented), and applied his mathematical understanding to the mysteries of the night sky. In so doing, he developed his theory of a system in which the Earth, like all the planets, revolved around the sun, and which simply and elegantly explained the curious retrograde movements of the planets.

Copernicus wrote his theory in *De Revolutionibus Orbium Coelestium* ("On the Revolutions of the Celestial Orbs"). The book was completed in 1530 or so, but it wasn't published until the year he died, 1543. It has been suggested that Copernicus knew the publication would incur the wrath of the Catholic church and he didn't want to deal with problems so he didn't publish his theory until he was on his death bed. Legend has it that a copy of the printer's proof was placed in his hands as he lay in a coma, and he woke long enough to recognize what he was holding before he died.

Tycho Brahe (1546 – 1601) was born in a part of southern Sweden that was part of Denmark at the time. While attending the university to study law and philosophy, he became interested in astronomy and spent most evenings observing the stars. One of Tycho Brahe's first contributions to astronomy was the detection and correction of several serious errors in the standard astronomical tables. Then, in 1572, he discovered a supernova located in the constellation of Cassiopeia. Tycho built his own instruments and made the most complete and accurate observations available without the use of a telescope. Eventually, his fame led to an offer from King Frederick II of

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Denmark & Norway to fund the construction of an astronomical observatory. The island of Van was chosen and in 1576, construction began. Tycho Brahe spent twenty years there, making observations on celestial bodies.

During his life, Tycho Brahe did not accept Copernicus' model of the universe. He attempted to combine it with the Ptolemaic model. As a theoretician, Tycho was a failure but his observations and the data he collected was far superior to any others made prior to the invention of the telescope. After Tycho Brahe's death, his assistant, Johannes Kepler used Tycho Brahe's observations to calculate his own three laws of planetary motion.

In 1600, Johannes Kepler (1571 – 1630) began working as Tycho's assistant. They recognized that neither the Ptolemaic (geocentric) or Copernican (heliocentric) models could predict positions of Mars as accurately as they could measure them. Tycho died in 1601 and after that Kepler had full access to Tycho's data. He analyzed the data for 8 years and tried to calculate an orbit that would fit the data, but was unable to do so. Kepler later determined that the orbits were not circular but elliptical.

Kepler's Laws of Planetary Motion

1. The orbits of the planets are elliptical.
2. An imaginary line connecting a planet and the sun sweeps out equal areas during equal time intervals. (Therefore, the earth's orbital speed varies at different times of the year. The earth moves fastest in its orbit when closest to the sun and slowest when farthest away.) Kepler's Second Law of Planetary Motion was calculated for Earth, then the hypothesis was tested using data for Mars, and it worked!
3. Kepler's Third Law of Planetary Motion showed the relationship between the size of a planet's orbit radius, R (12 the major axis), and its orbital

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period, T. $R^2=T^3$ This law is true for all planets if you use astronomical units (that is, distance in multiples of earth's orbital radium and time in multiples of earth years). Kepler's three laws replaced the cumbersome epicycles to explain planetary motion with three mathematical laws that allowed the positions of the planets to be predicted with accuracies ten times better than Ptolemaic or Copernican models.

Galileo and Newton

Galileo Galilei (1564-1642) was a very important person in the development of modern astronomy, both because of his contributions directly to astronomy, and because of his work in physics. He provided the crucial observations that proved the Copernican hypothesis, and also laid the foundations for a correct understanding of how objects moved on the surface of the earth and of gravity. One could, with considerable justification, view Galileo as the father both of modern astronomy and of modern physics.

Galileo did not invent the telescope, but he was the first to turn his telescope toward the sky to study the heavens systematically. His telescope was poorer than even a cheap modern amateur telescope, but what he observed in the heavens showed errors in Aristotle's opinion of the universe and the worldview that it supported. Observations through Galileo's telescope made it clear that the "earth-centered" and "earth doesn't move" solar system of Aristotle was incorrect. Since church officials had made some of Aristotle's opinions a part of the religious views of the church, proving Aristotle's views to be incorrect also pointed out flaws in the church.

Galileo observed four points of light that changed their positions around the planet Jupiter and he concluded that these were moons in orbit around Jupiter. These

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observations showed that there were new things in the heavens that Aristotle and Ptolemy had known nothing about. Furthermore, they demonstrated that a planet could have moons circling it that would not be left behind as the planet moved around its orbit. One of the arguments against the Copernican system had been that if the moon were in orbit around the Earth and the Earth in orbit around the Sun, the Earth would leave the Moon behind as it moved around its orbit.

Galileo used his telescope to show that Venus, like the moon, went through a complete set of phases. This observation was extremely important because it was the first observation that was consistent with the Copernican system but not the Ptolemaic system. In the Ptolemaic system, Venus should always be in crescent phase as viewed from the Earth because the sun is beyond Venus, but in the Copernican system Venus should exhibit a complete set of phases over time as viewed from the Earth because it is illuminated from the center of its orbit.

It is important to note that this was the first empirical evidence (coming almost a century after Copernicus) that allowed a definitive test of the two models. Until that point, both the Ptolemaic and Copernican models described the available data. The primary attraction of the Copernican system was that it described the data in a simpler fashion, but here finally was conclusive evidence that not only was the Ptolemaic universe more complicated, it also was *incorrect*.

As each new observation was brought to light, increasing doubt was cast on the old views of the heavens. It also raised the credibility issue: could the authority of Aristotle and Ptolemy be trusted concerning the nature of the Universe if there were so many things in the Universe about which they had been unaware and/or incorrect?

Galileo's challenge of the Church's authority through his refutation of the Aristotelian concept of the Universe eventually got him into deep trouble. Late in his life he was forced, under threat of torture, to publicly recant his Copernican views and spent his

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