## CHAPTER 4 - ASTRONOMY - THE BEGINNING OF THE SCIENCES

We have no record of when humans began the systematic study of forces and motion on earth, but it seems likely that they began to study the motion of the heavenly bodies fairly early, perhaps shortly after the Flood. Though Genesis 1:14-15 says that during the Creation week, "God said, Let there be lights in the firmament of the heaven to divide the day from the night; and let them be for signs, and for seasons, and for days, and years…", the first mention of harvests and varying temperatures is found shortly after Noah and his family left the Ark over 1500 years later. At that point God promised "While the earth remaineth, seedtime and harvest, and cold and heat, and summer and winter, and day and night shall not cease." (Gen 8:22). Perhaps crops previously grew all year long.

Visual #4-1

### I. THE BEGINNINGS OF ASTRONOMY.

If you watch the sky for several hours at night, you will see almost all the stars seem to move counterclockwise from east to west. Most ancient observers thought this was because the stars were moving around us, though we now know it is because the earth is turning on its axis of rotation. The North Star does not seem to move because it lines up with the axis.

If you look at the sky at the same time every night, you will see that the stars rise about four minutes earlier. After six months, many of the stars visible in the summer have dropped below the horizon and have been replaced with a different group. After a year, though, the stars are back in their original position.

Despite evolutionary ideas picturing them as dumb brutes not much advanced beyond the apes, ancient humans were quite intelligent. Many ancient cultures (e.g., Babylonians, Mayans, Chinese, Egyptians, Indians, Persians, Greeks) studied the stars very carefully and used their positions to predict when the growing season would begin, when rivers were likely to reach flood stage, and so on. They each selected a day to mark the beginning of the new year and were able to predict eclipses of the sun and moon. In particular, the Babylonians were known for making very accurate tables of the locations of the stars and planets.

### II. THE PSEUDO-SCIENCE OF ASTROLOGY.

Besides agriculturally useful information, the ancient people also came up with elaborate ideas about the effect of the heavenly bodies on people's lives. Few today claim that the systems of astrology they developed are scientific, but some of the terminology is still used in astronomy.

Visual #4-2

Visual #4-3

Many ancient cultures divided the stars into groups called constellations, named after some animal, person, or god they thought was outlined by the stars in that group. There are different names around the world, but the ones assigned in Europe and the Americas came to us because the conquests of Alexander the Great spread Greek culture throughout Europe, North Africa, and west Asia as far as India. Some of the names of the Greek gods were later replaced by their Roman equivalents, e.g., Jupiter instead of Zeus, Venus instead of Aphrodite, and do on.

- The constellation Cancer is supposed to resemble a crab.
- Orion is supposed to resemble the mythical Greek hunter of that name.
- Leo is supposed to look like a lion.
- Andromeda is supposed to look like a chained maiden.
- Cassiopeia is supposed to look line the mythical queen of that name.
- Perseus and Hercules are named for those mythological characters.
- Though it may not be as evident to us, the Greeks thought that Ursa Major and Ursa Minor showed the outline of bears and Canis Major and Canis Minor looked like large and small dogs.

There are dozens of constellations in the Greek system, as well as dozens in each of the systems passed down from other cultures around the world. (The constellations in the Southern and Northern Hemispheres are completely different from each other because they are on opposite sides of the Equator.)

Visual #4-4

The actions of the heavenly bodies were often taken as omens of things to come – births and deaths of royalty, military success or failure, and so on. Many people still rely on their horoscopes, which claim to tell their future based on the alignment of the heavenly bodies. Though it is impossible to verify, it is commonly thought that astrology began with the ancient Babylonians, whose system later became the basis of the ones used in many other cultures.

**A. CHALDEANS.**

The Bible tells us in Gen. 10:8-11 that Nimrod founded the city of Babel. A number of world empires later grew out of it. Babylon (the same Hebrew word as Babel) waxed and waned in importance several times, becoming most prominent under Nebuchadnezzar. Babylonians included a group called Chaldeans, which included many highly educated and influential astronomers and astrologers. They were also prominent in the Assyrian and Medo-Persian empires.

Daniel Chapter 2 shows that Daniel was very familiar with the Chaldeans. He was influential enough that they seem to have been familiar with the prophetic timetable he recorded in Daniel 9:24-25. Centuries later, some of the Chaldeans (known to us as Magi) were able to determine from his writings that the time for the Messiah's birth had arrived. They followed the stars, but Daniel merely recorded the revelation given him by God.

**B. THE ZODIAC.**

Visual #4-5

The systems around the world in which the constellations are divided into twelve groups, represented by the signs of the zodiac, are believed to be based on the system originated by the ancient Babylonians.

- Rather than basing their numbering system on ten as we do, the Babylonians used the number 60. (We still use this number in dividing hours into minutes and seconds.) They are commonly believed to have been the ones who decided to divide a circle into 360 degrees.

  The stars were believed to orbit the earth, going through all 360 degrees once a year. This led to a problem; it takes about 365.25 days for the stars to go 360 degrees and return to their same apparent positions.
- The moon was a convenient reference, but the number of times it orbits the earth each year is not a multiple or factor of 360. If we draw a line from the earth to the sun, it returns to the same relative position about 12.4 times a year (every 29.5 days). However, if we draw a line from the earth to specific stars, it returns to the same relative position about 13.4 times a year (every 27.3 days).

Rather than use inconvenient numbers such as these, the earliest astronomers and astrologists decided to divide the year into 12 parts of roughly equal length. They drew an imaginary line from the earth through the sun to the distant stars and constellations. Those that were on the line were said to be "in" the zodiac. They divided the zodiac into 12 roughly equal segments of about 30 degrees each. During the time the sun blocked a particular group of stars, that group was said to be in that sign of the zodiac.

Though astrologers regard the zodiac as something mystical, NASA recently published a study showing that not only did it start out wrong – there are not 12 evenly spaced constellations – but it has become more wrong because the earth's axis wobbles (*precesses*) slightly. Some objects that were in the zodiac thousands of years ago are above or below it now, and some that were not in it are now. Though astrologers still use the same 12 signs of the zodiac as the ancients did, there should actually be 13. Ophiuchus should be included.

Below is a list of the traditional dates used in horoscopes, as compared with NASA's observations of when the constellations in those signs actually align with the imaginary line through the sun.

| | **Traditional Zodiac** | | **NASA dates** | |
|---|---|---|---|---|
| Capricorn | 12/21-1/20 | 31 days | 1/20 - 2/16 | 27 days |
| Aquarius | 1/21-2/18 | 29 days | 2/16 - 3/11 | 23 days |
| Pisces | 2/19-3/20 | 30 days | 3/11 - 4/18 | 38 days |
| Aries | 3/21-4/19 | 30 days | 4/18 - 5/13 | 25 days |
| Taurus | 4/20-5/20 | 31 days | 5/13 - 6/21 | 39 days |
| Gemini | 5/21-6/20 | 31 days | 6/21 - 7/20 | 29 days |
| Cancer | 6/21-7/22 | 31 days | 7/20 - 8/10 | 21 days |
| Leo | 7/23-8/22 | 31 days, | 8/10 - 9/16 | 37 days |
| Virgo | 8/23-9/22 | 31 days | 9/16 - 10/30 | 44 days |
| Libra | 9/23-10/22 | 30 days | 10/30-11/23 | 24 days |
| Scorpio | 10/23-11/21 | 30 days | 11/23-11/29 | 6 days |
| | Ophiuchus | | 11/29-12/17 | 18 days |
| Sagittarius, | 11/22-12/21 | 30 days | 12/17-1/20 | 34 days |

(NASA, anonymous article, 2016)

## III. THE ROOTS OF MODERN ASTRONOMY.

Though astrology is based in superstition, it did eventually lead to astronomy.

Much of modern astronomy traces back to the Greek mathematicians and philosophers in the centuries before Christ. Though Greek culture as a whole involved a great deal of superstition (see Acts 17:22), some of the philosophers were seeking predictable descriptions of the motion of the heavenly bodies that did not depend on the whims of the gods.

Some observations that have not changed since ancient days: the sun is at its highest point every 24 hours and the moon is in approximately the same position between us and the sun about every 29.5 days. The stars rise earlier about 4 minutes every day, and return to their same positions in the sky every 365.25 days. Some of the heavenly bodies move in the same direction as the stars most of the time but occasionally seem to move backwards. (The Greek word for these "wanderers" was *planet*.)

Visual #4-6

We now realize that all these phenomena (except for some aspects of the moon's motion) occur because the earth is turning. However, many ancient thinkers believed the earth was stationary and everything else was moving around us. Since the earth was placed at the center, this model is called *geocentric*. One of the proponents of geocentrism around 400 BC was Eudoxus of Cuidus. He believed that the planets, sun, and moon all circled earth, each attached to its own invisible crystalline sphere. (The idea that the spheres rubbed against each other was the source of the expression "music of the spheres.") The occasional retrograde motion of the planets was explained by saying that there were dozens of spheres, not all of which went all the way around the earth. The objects in the spheres that did not go all the way around us would seem to move forward for a while, then backward, then forward again and so on.

### A. ARISTOTELIAN IDEAS

The Greek philosopher who had the greatest impact on Western civilization was probably Aristotle (384-322 BC). His ideas were passed down to us because for about 16 years he tutored Alexander the Great (356-323 BC), who in turn spread what Aristotle had taught him over much of the then-known world. These ideas were taught as fact in Europe, north Africa, and west Asia for almost 2,000 years.

Aristotle was a careful observer of nature, recording detailed observations of living things at close range. However, he could not do the same with objects in space. (The telescope would not be invented until thousands of years later.) Nevertheless, he used the system of logic he had invented (*Aristotelian* logic, which we still use today) to draw conclusions about the heavenly bodies. He decided that certain concepts were self-evident and drew logical inferences from them.

Unfortunately, some of his ideas blocked progress in astronomy for almost two thousand years. For instance:

- The heavens are perfect and unchanging.
- Whoever made the planets (the gods, perhaps) would have preferred the perfect shape of a sphere.

> The idea that the earth is flat has been known to be false since the earliest days of astronomy. Every time there was an eclipse of the moon, no matter what its position in the sky, the earth always cast a round shadow on it. This could only be explained if the earth was a sphere.

- Except for the "wandering stars" (the planets), all the other stars had to be the same distance from the earth.

Visual #4-7

Aristotle reasoned that if the stars were different distances he should be able to see at least a small amount of *parallax* between some of the stars as they orbited the earth over the course of a year. Parallax is the apparent change in position of an object compared to other objects that are much farther away or much closer. To see how it works, hold your thumb out at arm's length and look at an object much farther away, perhaps a distant light or tree. If you alternately close your left eye, then right, then left and so on, the thumb seems to jump back and forth. Or, if you focus on your thumb while alternately closing your eyes, the distant object seems to jump back and forth.

Visual #4-8

This is a perfect example of how a false premise in logic can lead to a false conclusion. Aristotle's idea could be expressed as

If I cannot see something, then it does not exist.
I cannot see parallax.
Therefore, parallax does not exist.

The next step would be to reason that

If the stars are different distances then there will be parallax

which follows the structure If P, then Q.

We can use this statement to construct the *contrapositive*, in which the "if" and "then" parts are reversed and both made negative. The contrapositive of

If P, then Q is If not Q, then not P.

we could therefore validly conclude

If there is no parallax, then the stars are not different distances.

Aristotle's logic was flawless, but his vision was not sharp enough. After the telescope was invented many centuries later, it was not long until astronomers were able to detect parallax. Since Aristotle's premise was false, his conclusion was too.

Visual #4-9

> A similar situation exists with the concept of vestigial organs which we will see in a later chapter. Many scoffers think that if they do not know the function of an organ it does not have one.

- The stars could not be very far away from the earth. If they were, they could not move fast enough to orbit all the way around it each night.

### B. FURTHER DEVELOPMENT OF THE GEOCENTRIC MODEL

Alexander memorialized his own name by founding the city of Alexandria ca. 331 BC after he conquered Egypt. It became the center of Greek learning and had one of the largest libraries in the world. Many of the great developments in mathematics took place in there, e.g., the development of Euclidean geometry and the calculation of the earth's circumference by Eratosthenes.

Visual #4-10

Two famous men named Aristarchus were associated with Alexandria. The first (310-230 BC) was an astronomer and mathematician who followed the teaching of the earlier philosopher Philolaus. (The second, 220-143 BC, became the librarian and was known as a poet and grammarian.) Aristarchus the astronomer said that a heliocentric (sun centered) model made more sense than a geocentric one. However, because of Aristotle's prestige, his work was largely ignored. Aristarchus also used principles of geometry to estimate the distance to the sun and moon. He did not have accurate enough data to get the presently accepted answer, but his methodology was good. Hipparchus refined his calculations of the distance and size of the moon in the 2nd century BC, though he relied on a geocentric model.

Meanwhile, the Roman Republic/Empire was replacing the Greeks as the world's dominant power. Rome incorporated much of the knowledge accumulated by the Greeks into its own educational system. Astronomy continued, though some of the names of the Greek gods were replaced by those of the Romans, e.g., Zeus by Jupiter, Aphrodite by Venus, Ares by Mars, and so on.

Claudius Ptolemaeus (100-170 AD), better known as Ptolemy, lived in Alexandria several centuries after Aristarchus and Hipparchus. He believed that the earth was the center of the universe. His contribution to the geocentric model was that he mathematically worked out the details of how the heavenly bodies could be moving on their own individual spheres. Later references to the geocentric model called it the Ptolemaic system.

### C. CONTRIBUTIONS OF ARABIAN ASTRONOMERS

Rome waned in influence over the next few centuries, leading into a period sometimes called the Dark Ages. There was little astronomical development in Europe. However, Arabian astronomers made detailed charts of the stars, many of whose Arabian names we still use such as Aldebaran, Altair, Betelgeuse, Deneb, Fomalhaut, Rigel, Spica, Vega, and many others. These were listed in the Book of Fixed Stars (*Suwar al-Kawakib al-Thabitah*) dated to about 964 AD.

## IV. THE HELIOCENTRIC MODEL.

As noted in the previous chapter, models can be useful in studying phenomena that are not subject to direct testing. However, the fact that we can devise a model that seems to work does not necessarily mean that it is completely correct. For example, the planetary model of the atom helps us picture what is going on but nobody thinks it is absolutely correct.

### A. COPERNICUS. (1473-1543)

Visual #4-11

For over a millennium after Ptolemy put forth his model (which was based on Aristotle's geocentric ideas), there was not much development in describing the motion of the stars. Meanwhile, the Roman Empire had declined to insignificance and the Roman Catholic Church became one of the dominant political powers in Europe. The Catholic Church decided that Aristotle and Ptolemy were correct. Anyone who disagreed was in danger of execution.

Nicolaus Copernicus was a very religious man, born into a well-to-do family in Poland in 1473. His uncle was able to get him a position at the University of Bologna, where he became an assistant to the principal astronomer. Copernicus's duties included helping to make astrological predictions for the people of the city. While in his twenties, Copernicus realized that a model in which the sun was the center of the universe could describe the behavior of the planets and stars with far simpler mathematics than the Ptolemaic model. However, he could not back up his ideas with experimentation. Perhaps because he feared for his life, he did not publish his work until shortly before his death. (Westman, n.d.)

**B. TYCHO BRAHE.** (1546-1601)

Visual #4-12

The Danish astronomer Tycho Brahe was a devout Christian who does not seem to have been greatly concerned with geocentrism or heliocentrism. He is thought to have believed in a hybrid model in which the moon and sun circled the earth, but the other planets circled the sun.

> Historical note: For most of Tycho's life he wore a prosthetic nose. His real nose was cut off in a duel with a cousin in 1566. He later married and had six children.

The telescope was not invented until seven years after Tycho's death, but he was known for recording the positions of the heavenly bodies in meticulous detail. He began his observations in a private observatory on the land he inherited from his family. His 1572 discovery of a new star (a supernova) in the constellation Cassiopeia shocked those who followed Aristotle's idea that the universe was unchanging. His 1577 discovery of a comet was also shocking: it seemed to penetrate several of the celestial spheres by orbiting the sun instead of the earth.

As Tycho gained fame the king of Denmark gave him an island to do his work and furnished him with financial support. He had special instruments made that allowed him to record the positions of hundreds of heavenly bodies with a precision that would not be exceeded for many years. (Eggen, n.d.)

**C. JOHANNES KEPLER.** (1571 - 1630)

Visual #4-13

Tycho recorded vast numbers of observations, but did not know what to do with the numbers. Near the end of his life he took on the German mathematician Johannes Kepler to help him analyze the motion of Mars. After Tycho's death, Kepler gained access to all of his data and was able to analyze the motion of the other planets as well.

Kepler has to be considered one of the greatest mathematicians of all time because he was able to discern the patterns in the data inherited from Tycho. Besides being an eminent astronomer and mathematician, he was a devout Christian and said that he made his discoveries by "thinking God's thoughts after Him."

Kepler applied statistical analysis to the Mars data and found that it could be represented by the equation of an ellipse. The same held true for all the other planets.

1. **Kepler's First Law of Planetary Motion.**
   An ellipse is similar to a circle except that instead of a single center, it has two focal points. Kepler found that the orbit of each planet was not a circle but instead an ellipse with the sun at one focus. He did not know why the other focus existed, though we would now say it is the center of mass of all the other planets. (Though Kepler was the first one to demonstrate this mathematically, Hipparchus in the 2nd century BC had foreseen the possibility that the orbits might be elliptical.)
2. **Second Law of Planetary Motion.**
   As he studied the data, Kepler realized that the planets move at different speeds at different times of the year. Visualizing their elliptical orbits, he determined that if he drew a line from the planet to the sun at the beginning and end of a specific interval of

time, it would trace out a more or less triangular shape with a curved end farthest from the center. This would enclose a certain area. Then, selecting a different time of the year but using the same interval, he found that the second shape, though it might be longer or wider than the first, would enclose the same area as the first.

3. **Third Law of Planetary Motion.**

Visual #4-14

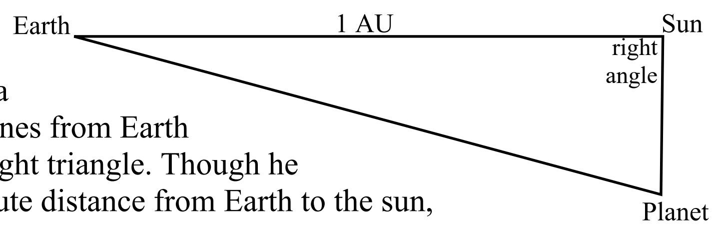
Comparing the equations of the orbits of all the planets, he found that there was a clear relationship between their distances from the sun and the amount of time it took each one to make a single orbit (its orbital period).

We might wonder how he could tell how far away each planet was from the sun. Though the technology to determine the absolute distance did not exist until the invention of radar in the $20^{th}$ century, trigonometry (the study of triangles) had been available for thousands of years. He was able to use trigonometric functions such as the *tangent* to compare the other orbital distances to that of the earth, which is taken as one astronomical unit (AU).

Though Tycho did not have the advantage of using a telescope to collect his data, he used the best equipment available to record angles and positions of the heavenly bodies with an amazingly high degree of precision.

> A circle is divided into 360 degrees. Each degree is divided into 60 minutes. Each minute is divided into seconds. Thus, one second of arc = 1/3600 of a degree. Tycho's *brass azimuthal quadrant* allowed him to observe with a precision of less than 48 arc seconds, which is ¾ of 1 minute of arc, or less than 1/75 of a degree. (High Altitude Observatory, n.d.) This is about 1/27,000 of the way around a circle.

Imagine a triangle with the earth at one vertex, the sun at another, and the planet in question at the third.




After Tycho's death, Kepler could use such a figure to get a fairly good idea of when the lines from Earth to the Sun to Mars formed a right triangle. Though he had no way to know the absolute distance from Earth to the sun, he was able to use trigonometry to estimate the ratios of the sides.

Using Tycho's data, he calculated the angle nearest the earth. He was then able to use the tangent of that angle to calculate that whatever the distance from the Earth to the sun (1 AU), the distance to Mars was 1.524 times as much. He later calculated the relative distance from Mercury to the sun as 0.387 AU, Venus as 0.723 AU, Jupiter as 5.20 AU, and Saturn as 9.54 AU. (Stern, n.d.)

Using these relative distances, Kepler formulated his Third Law of Planetary Motion. It says basically that for any object in orbit around a central body, the relationship between distance and period is a constant as calculated in the equation $k = \frac{R^3}{T^2}$ where $R$ is the average radius of the orbit and $T$ is the period. He did not know why the ratio was constant for all objects orbiting the same central body. Newton later determined that it was because of the gravitational attraction of that body.

This equation would apply equally well to any two objects orbiting the same body. Thus, if we know the radius and period of one of the orbits and we observe the period of the other, we can easily determine the radius of the other orbit. That is, for any two objects orbiting the same body, $\frac{R_1^{\ 3}}{T_1^{\ 2}} = k = \frac{R_2^{\ 3}}{T_2^{\ 2}}$. We can eliminate $k$ and use any three of the other values to find the fourth.

After over 400 years, we still use Kepler's $3^{rd}$ Law to plan the movement of space probes.

**D. GALILEO GALILEI.** (1564-1642)

Galileo Galilei of Pisa, Italy was both a brilliant scientist and a devout Christian. He was quoted as saying, "God is known by nature in his works, and by doctrine in his revealed word."

Visual #4-15

The first known application for a patent on a telescope was submitted in 1608 by the Dutch lens maker Hans Lippershet. After reading a description of Lippershet's instrument, Galileo constructed his own more powerful version.

Galileo's telescope did not have sufficient magnification for him to detect stellar parallax, which would have shown that the stars were different distances. (That did not happen until the early 1800s.) Nevertheless, as soon as he began to use his telescope to study the heavens, he found that many of Aristotle's ideas were wrong.

- The moon is not perfectly smooth but instead is rough and uneven.
- The sun is not perfectly uniform but has sunspots.
- There were four moons in orbit around Jupiter visible through a telescope.
- There were many more stars in the sky than previously thought. The Milky Way was not a cloud but was composed of vast numbers of stars.
- Venus goes through phases just as the moon does.
- Despite Aristotle's belief that the heavens are unchanging, Galileo observed a number of comets passing through the solar system.

Galileo published several works, e.g. *Dialogue Concerning the Two Chief World Systems, Ptolemaic & Copernican* in support of the Copernican (heliocentric) model. His ideas contradicted Aristotle – and the Catholic Church – so blatantly that in 1633 the church summoned him to Rome to face the Inquisition. Under threat of death or imprisonment, he was forced to recant. (Van Helden, 2022) Technically, he remained under house arrest for the rest of his life.

Nothing Galileo said contradicted the Bible. Ironically, the Catholic Church condemned him because he contradicted the word of Aristotle, a pagan Greek philosopher.

**E. ISAAC NEWTON.** (1642-1726)

Visual #4-16

Isaac Newton was born the same year that Galileo died. Though best known for his scientific work, he wrote more on the subject of religion than he did on science.

Because he worked with both theory and experimentation, Newton is widely considered the greatest scientist of all time and is often called the Father of Classical Physics. (By comparison, Einstein was purely a theoretical physicist.) He is credited with discovering the previously mentioned Law of Gravity, the First, Second, and Third Laws of Motion, and many principles still important to science. We will consider many of his discoveries in other areas besides astronomy later in this chapter and the next.

Before Newton, it was unclear why the planets followed the paths that they did. Some actually thought that the sun was pushing them.

Newton concluded that everybody else was wrong. He wrote that one day as he was sitting in a garden he began to wonder about why both the moon and an apple that fell in front of him were attracted toward the center of the earth. (No, it did not hit him on the head.) He realized that no matter where anything fell on the earth, it would always fall toward the center. He assumed that there must be a force, gravity, that acts between any two bodies and does not require contact. Using the concept of gravity, he was able to show that it was the explanation for Kepler's Laws. He also worked those laws out independently by using his newly invented calculus.

Newton was able to demonstrate that gravity was the explanation for why all the planets followed their orbits. The sun was trying to pull them in, but their inertia tried to make them keep moving forward.

One of Newton's inventions that greatly advanced astronomy was the reflecting telescope. Previous *refracting* telescopes used two lenses and distorted images (chromatic aberration) because they refracted colors. This limited their ability to magnify clear images. Newton invented a different kind of telescope that used a concave mirror to gather light and a flat diagonally oriented mirror to direct the light into a small eyepiece. This eliminated the problem of chromatic aberration and increased the potential magnifying power of the telescope. Though there have been many refinements, the Newtonian design is still the basis of many modern portable telescopes.

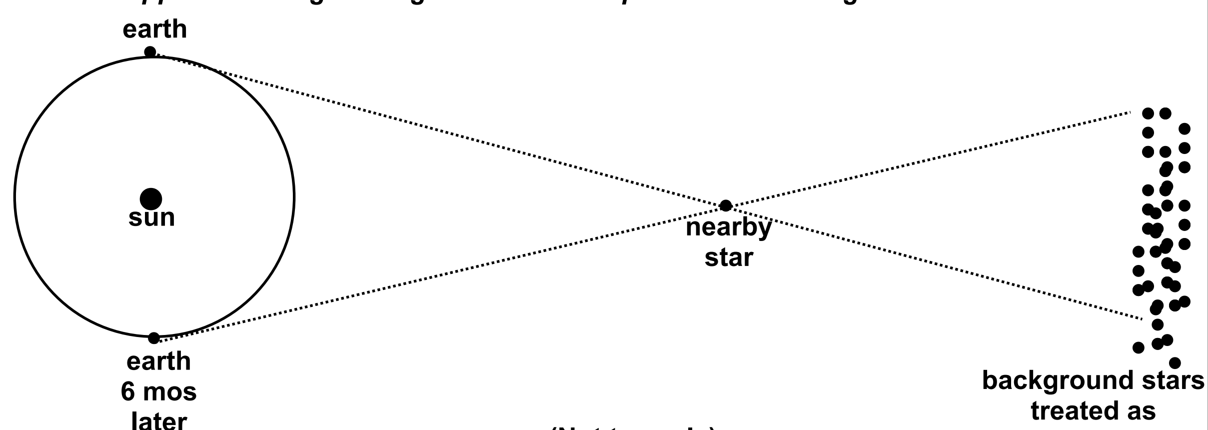
**F. STELLAR PARALLAX.**

In the century following Newton's death, there were not many theoretical discoveries in astronomy. Much of the progress consisted of improvements in telescopes. For instance, in 1869 the Dutch astronomer Christiaan Huygens was able to see the rings of Saturn clearly for the first time. (He was also the first to calculate the speed of light. Though the value he obtained, 131,000 mi/sec, was later determined to be too low by a third, it still showed that the speed was finite.)

Ever since the days of Aristotle thousands of years earlier, scientists had never been able to detect stellar parallax, which would have showed that the stars were not all at the same distance from Earth. It was not until the 1830s that anyone finally reported observing it. In 1832 Manuel John Johnson measured a parallax for Alpha Centauri, followed by Thomas Henderson in 1832-1833. In 1838 Friedrich Wilhelm Bessel reported that he had observed parallax in 61 Cygni.

Visual #4-17

***Parallax - apparent change in angle of a star compared to the background stars 6 months later***




**(Not to scale)**

Parallax is based on arcs, which are part of circles. A circle has 360 degrees. Each degree has 60 minutes, each of which has 60 seconds. Thus, one parallax second equals

$\frac{1}{360} \times \frac{1}{60} \times \frac{1}{60}$ , or 1/1,296,000 of a circle.

To measure parallax, we take measurements of the position of a star compared to the background stars, treated as infinitely distant. We repeat the measurement six months later, at the opposite end of our orbit around the sun. The observed difference is twice the actual parallax.

If we see a difference in parallax of one second of arc, we say the distance is one *parsec*.

One parsec is about 3.26 light-years. A light year is not a unit of time, but distance. It is the distance light travels in a year, about 5,800,000,000,000 or 5.88 trillion miles. A parsec is about 19.2 trillion miles.

The smaller the parallax, the farther the object. The nearest star to Earth, Proxima Centauri, has a parallax of 0.772 arc seconds, or about one millionth of a circle. Alpha Centauri has a slightly lower parallax of about 0.742. Barnard's Star has a parallax of about 0.549 arc sec, and Lalande 21185 has a parallax of about 0.392 (Anonymous, "Distances to Nearby Stars").

Only the most powerful telescopes are able to resolve such small angles. Even then, once we go past about 50 light years the less certain we can be about the measurements.

The detection of stellar parallax not only showed that the stars were different distances from earth, but also that they could not possibly be moving while the earth stood still.

- If they were orbiting us, they would have to go all the way around every 24 hours.
- Though no one had been able to measure the distance, the stars were previously thought to be no more than several million miles away from Earth. Parallax showed that the distance was at least billions of miles.
- Using basic geometry we can tell that any object more than about 2.5 billion miles away (200 million miles closer than Neptune) would have to cover a distance described by the equation for the circumference of a circle, $c = 2 \pi r$ during each 24 hour period. If it were about as far as Neptune, the circumference of its orbit would be $2 \pi$ x 2.7 billion, or almost 17 billion miles per day. Since there are 86,400 seconds in a day, it would have to move faster then the speed of light to make it around every day. This showed that the earth had to be rotating rather than the rest of the universe.

A universe in which the heavenly bodies orbited a stationary Earth would be limited in size, but a heliocentric one would not.

**G. ABSOLUTE DISTANCES OF THE SUN AND PLANETS.**

Visual #4-18

Ever since Kepler, astronomers were able to determine the *relative* distances between the planets using parallax and Kepler's Laws. However, they were not able to confirm those distances until the 1960s, several decades after the invention of radar. Radar was refined to become more and more powerful, until beams were developed that were strong enough to bounce off the moon, Venus, and Mars. Since radar travels at the speed of light (about 186,000 miles or 300,000 km per second), it was now possible to calculate the distances by using the time the radar signals took to bounce off those objects and return to earth. Once the first absolute distance was known, scientists were able to use Kepler's 3rd Law to determine the rest. (Goldstein, 1963; Pickering, 1965)

**H. MOTION OF THE SOLAR SYSTEM.**

The earliest models of the solar system were based on the idea that the earth was the center of the universe. Those of the 16th century and later placed the sun at the center. Though we still accept it as the center of the solar system, it is not the center of the universe.

Visual #4-19

Ps. 19:6 says of the sun, "His going forth is from the end of the heaven, and his circuit unto the ends of it: and there is nothing hid from the heat thereof." Skeptics point this out as an error in the Bible, because the sun does not orbit the Earth. However, the verse does not say that it does.

In 1965 Penzias and Wilson of Bell Labs reported that while calibrating a radio telescope they had discovered microwave background radiation that seemed to be of equal strength in every direction. (They later received the Nobel Prize for their discovery.) The radiation, known as the Cosmic Microwave Background or CMB, had an energy level just above absolute zero, at 2.735 Kelvins. (Shu, 2019.)

In a later chapter the discussion of waves will give more details on the phenomenon of Doppler shifts. Of note at this point is that the CMB seems to furnish a frame of reference through which the sun and the entire solar system are moving in a lengthy orbit at more than 550 km/sec. (Alfven & Mendis, 1977; Smoot et al., 1977) That is, the sun *is* making a circuit through the heavens.

## I. PRACTICAL NAKED-EYE ASTRONOMY.

### 1. Measuring the Earth's tilt.

Visual #4-20

A geocentric model has a hard time explaining why we have summer and winter. However, if we orbit the sun instead of it orbiting us, it is easy to explain.

The earth's axis is not perpendicular to the plane of its orbit, but is tilted at an angle averaging about 23.5 degrees. This is easy to test, as follows.

- Use a compass to determine which way is west.
- Pick a convenient place to watch the sunset every day. From that spot, note the angle either north or south of west at which the sun sets every day. (If you are an early riser, sunrise in the east works just as well.)

Over the course of a year the angle changes about 46 or 47 degrees, from its value farthest toward the south to its value farthest toward the north. The tilt of the axis is half of the difference between the extremes.

### 2. Why there are seasons.

At the closest, Earth is about 91.3 million miles from the sun. At the farthest, the distance is about 94.5 million miles. Summer occurs in the Northern hemisphere, when we are farthest away, because the tilt of the earth's axis plays a much more significant role than the distance.

> The fact that summer, when we are farther from the sun, is a bit longer than winter, when we are closer, fits perfectly with Kepler's Second Law. An object farther from the body it is orbiting moves slower.

When we are on one side of the sun and the north end of our axis points toward it, the sun's rays hit the northern hemisphere more directly and it is summer. (Meanwhile, it is winter in the southern hemisphere.) When we are on the other side of the sun so that the north end of the axis points away from it, it is winter in the northern hemisphere and summer in the southern.

From the perspective of the northern hemisphere, the day when the axis points most directly at the sun is the longest day of the year. This is called the *summer solstice*. The shortest day, the *winter solstice*, occurs when the axis points away from the sun. In between the solstices is a day in the spring and one in the fall when the north and south ends of the axis are equally distant from the sun. Day and night are of equal length on these two days, the *equinoxes*.

Some aspects of astronomy have to do with other areas of science and will be brought up in later chapters.

- For example, a study of the origin of life that does not deal with the question of whether there are planets in space would be incomplete.
- A study of the size of the universe automatically requires some familiarity with waves and red shifts.
- The study of the age of the universe logically involves considering how long it took the light from the stars to reach the earth.

**CHAPTER 4 REVIEW QUESTIONS**

1. Why does the North Star not seem to move like all the other stars? ______________________

______________________________________________________________________________

2. What does astrology try to predict? ________________________________________________

______________________________________________________________________________

3. Which civilization is believed to have decided that there were 360 degrees in a circle? ______

______________________________________________________________________________

4. What is a geocentric model of the solar system? ______________________________________

______________________________________________________________________________

5. What is a heliocentric model of the solar system? ______________________________________

______________________________________________________________________________

6. Why did Aristotle believe there was no such thing as parallax of the stars? ________________

______________________________________________________________________________

7. What did Aristotle believe about the distances to all the stars? __________________________

______________________________________________________________________________

8. Was Copernicus able to back up his ideas about the solar system through experimentation? _______________

9. What did Tycho Brahe observe that was so shocking to those who believed the universe was unchanging? ____________________________________________________________________

10. How did Kepler formulate his Laws of Planetary Motion? ______________________________

______________________________________________________________________________

11. What were some of the shocking things Galileo observed as he looked at the planets with his telescope? _____________________________________________________________________

12. What great discovery did Newton make regarding the motion of the planets? ______________

______________________________________________________________________________

13. When was stellar parallax first observed? ____________________________________________

14. A light year is a measurement of what? ______________________________________________

15. When were scientists first able to directly measure the distances to Mars and Venus? ________

16. What did they use to make this observation? _________________________________________

17. Does the Bible say the sun orbits the earth? __________________________________________

18. What does the earth's tilt have to do with why summer is warmer in the northern hemisphere?

______________________________________________________________________________

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