

# Chapter 0

## Charting the Heavens

### The Foundations of Astronomy

#### 0.1 The “Obvious” View

- Our Place in Space
  - Humans live on a large rock called a planet
  - Planets go around giant balls of gas called stars
  - Stars are tiny grains of sand within a galaxy
  - Galaxies are tiny clouds within a nearly infinite universe
    - **Astronomy** is the study of the universe
  - There are only 3 things that were visible to ancient humans
    - The Sun – Noticed that the sun moved in the sky and linked to the temperature and weather patterns on earth to the sun’s location
    - Moon – Noticed that the moon repeats its appearance in an exact amount of time and noticed that it affects things on earth as well
    - Stars – Noticed that some are bright, some are dim, some move a lot, some don’t seem to move at all, and that some would be visible at times but not visible at other times
- Constellations in the Sky
  - The brightest stars observable in ancient times were ‘grouped’ together by humans
    - **Constellations** are configurations of stars that appear to move together in the sky
      - There are 88 total constellations
  - Patterns were discovered with these groups of stars
    - Some of them are visible year-round
    - Some of them disappear and reappear at different times of the year
  - Tracking these groups of stars helped them know when to plant their food at the start of spring and when to harvest their food before the winter came
    - The constellations were the first calendars invented by humans to help them survive the long winters where they could not grow food
- The Celestial Sphere
  - The constellations seemed to move across the sky at night, but they moved together
    - The **Celestial Sphere** is the imaginary sphere the ancients thought all the stars resided on that moved around the fixed earth far out in space
    - Today we know that the Earth is spinning, causing it to appear like the stars are moving
      - **Rotation** is the spinning of an object around an internal axis
    - Despite being inaccurate in its original form, the Celestial Sphere is still used today as a good visual aid of how to view the positions of stars in the sky
      - The **North Celestial Pole** is the point in the sky where the extension of the North Pole on Earth meets the Celestial Sphere
      - The **South Celestial Pole** is the point in the sky where the extension of the South Pole on Earth meets the Celestial Sphere
      - The **Celestial Equator** is the circular plane thru the center of the Earth that is perpendicular to and halfway between two Celestial Poles
- Celestial Coordinates
  - Easiest way of locating stars in the sky is to specify the constellation and then rank the stars of that constellation in order of brightness using the Greek alphabet
    - Alpha, Beta, Gamma, Delta, Epsilon, Zeta, Eta, Theta, Iota, Kappa, Lambda...
    - This method works perfectly well for naked-eye Astronomy, but not if we want to be much more precise or if we have more stars in a constellation than the 24 Greek letters
    - **Celestial Coordinates** are numbers that give the precise location of anything the Celestial Sphere in the same way that GPS coordinates give us location on Earth or an address gives the location of a building within a city or town

- Measuring the Celestial Coordinates
  - **Declination** is the extension of the latitude lines for earth and are used to measure the location of an object north or south of the Celestial Equator
    - Measured in Degrees ( $^{\circ}$ ), Minutes ( $'$ ), and Seconds ( $''$ )
      - There are  $60''$  in  $1'$  of arc,  $60'$  in  $1^{\circ}$  of arc, and  $360^{\circ}$  in a complete circle
    - Celestial Equator is  $0^{\circ}$ , Celestial Poles are  $90^{\circ}$ , North is +, South is -
  - **Right Ascension** is the extension of the longitude lines for earth and are used to measure the location of an object east or west of the Sun at the instant of the Vernal Equinox
    - Measured in Hours (h), Minutes (m), and Seconds (s)
      - There are  $60^s$  in  $1^m$ ,  $60^m$  in  $1^h$ , and  $24^h$  in a complete circle
    - Sun at instant of Vernal Equinox is  $0^h$ , and increases to the east

## 0.2 Earth's Orbital Motion

- Day-to-Day Changes
  - The amount of time it takes for the Earth to rotate  $360^{\circ}$  around its axis is 24 hours.
    - The **Solar Day** is the amount of time it takes for the Sun to go from a specific location in the sky to the exact same location again
      - This is the 24 hours commonly referred to as a “day”
    - Today we know that the Earth is also moving in a path around the Sun
      - **Revolution** is the spinning of an object around an external axis
    - Since the Earth revolves around the Sun as well as rotates around its axis, the earth has to rotate slightly further than  $360^{\circ}$  in order to get the Sun back to the same location as it was the day before. This creates a different timeline for the Sun as it does for the stars, since the earth does not revolve around the stars as it rotates.
    - The **Sidereal Day** is the amount of time it takes for a star to go from a specific location in the sky to the exact same location again
      - The Sidereal Day is 3.9 minutes shorter than the Solar Day
        - This is why the stars appear shifted each day if charted at the same “time” (solar time). They go slightly further than  $360^{\circ}$  in 24 hours
- Seasonal Changes
  - Due to the revolution of the Earth around the Sun, the direction we see at night changes slightly each night. Over the course of a year, the Sun appears to trace a circle thru the Celestial Sphere although it is actually the Earth that does the  $360^{\circ}$  turn around the Sun
    - The **Ecliptic** is the circle traced in the Celestial Sphere by the apparent movement of the Sun throughout the year. 12 Constellations reside along this circle.
      - The **Ecliptic North Pole** is  $90^{\circ}$  north of the Ecliptic
      - The **Ecliptic South Pole** is  $90^{\circ}$  south of the Ecliptic
    - The **Zodiac** are the 12 Constellations that the Sun sweeps thru over the course of a year
      - The Zodiac signs are named for the constellation that we cannot see during that particular time of year due to the Sun being directly in our line of sight to it
      - In late February to early March, the constellation Pisces cannot be seen due to the Earth facing it only in the daytime
        - The Zodiac sign of people born during this time is Pisces
  - The Earth's axis does not point at  $90^{\circ}$  from the plane it orbits the Sun, but is sits at  $23.5^{\circ}$  less
    - This is why the Sun appears to move north in the summer and move south in the winter.
      - The Ecliptic is not along the Celestial Equator, but rather at an angle of  $23.5^{\circ}$  above it in the summer, and  $23.5^{\circ}$  below it in the winter
    - The sun appears to move north in the summer and move south in the winter
      - In reality, a different location on the Earth points directly at the Sun as our tilted planet revolves around it.
    - The **Summer Solstice** is the northernmost point the Sun reaches in the Celestial Sphere
      - This occurs on or near June 21<sup>st</sup> (365.25 day revolution)
    - The **Winter Solstice** is the southernmost point the Sun reaches in the Celestial Sphere
      - This occurs on December 21<sup>st</sup> (365.25 day revolution)





- Our eyes and brain do this exact same calculation between the view of our left and right eyes
  - If you find an object far away in your line of sight and place your finger at arms-length in front of you and close one eye, your finger will appear to be in a certain position.
  - If you then close that eye and open the other, the finger will appear to be in a different position relative to the object behind it
  - Your brain takes these two images and constructs an accurate image of the exact location of the finger in both the angle and distance.
  - **Parallax** is the apparent displacement of a foreground object relative to the background as the observers location changes.

In 200 B.C. the Greek philosopher Eratosthenes used triangulation to calculate the diameter of the Earth from the length of shadows that two towers cast on the ground on the Summer Solstice

- I. He measured the length of the shadows that two identical towers in different locations on the Earth on the longest day of the year.
  - Using triangulation, he was able to calculate the angle of the Earth between the two
  - Knowing that the Earth was basically a circle (Aristotle proved in 300 B.C.), he was able to use the geometric idea of similar shapes to calculate the diameter of the Earth

$$\frac{\text{Part of Small Circle}}{\text{Whole of Small Circle}} = \frac{\text{Distance on Large Circle}}{\text{Total Distance of Large Circle}}$$

$$\frac{2.7^\circ}{360^\circ} = \frac{\text{km between towers}}{\text{km around Earth}}$$

He calculated the circumference and radius of the Earth to be 40,000 km and 6,366 km...  
 Today with our modern technology we use 40,070 km and 6,378 km!

### 0.5 Science and the Scientific Method

- **Science** is a process for investigating the physical world based on natural laws and observed phenomena.
  - Progress in science is often slow and intermittent and can require a great deal of patience before significant progress is made.
- The earliest descriptions of the universe were based on mythology and imagination and made little attempt to explain the workings of the heavens in terms of testable ideas that come from collected information
  - Eventually certain people discovered that careful observation and testing of ideas was much more valuable in explaining and predicting observable events
- A **Theory** is a framework of ideas and assumptions that used to explain sets of observations and make predictions about the real world.
  - Theories must be continuously tested and changed if there is new observable evidence that cannot be explained using the current theory
  - A **Theoretical Model** is visual or mathematical explanation that accounts for the all of the known properties and observations of a particular topic
    - The model will make additional predictions or even predict how it would change under different circumstances, which can then be tested and verified or rejected
- The **Scientific Method** is a sequence of investigation, collecting observable information, theorizing, and experimenting to learn relationships in the natural world.
  - It is a continuous process that can be modified and changed at any point should new evidence or something that cannot be explained by current theories is discovered.
  - Scientific theories have several defining characteristics
    - They must be testable, and can be found invalid if new evidence contradicts them
    - They must be continually tested and their consequences tested as well
    - They should be simple and the simpler the idea the better
      - Occam's Razor is a principle that states if there are two different theories for the same phenomena that the best explanation is the most simple one