## 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
- 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 $60^{\prime \prime}$ in $1^{\prime}$ of arc, $60^{\prime}$ 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 $60^{\mathrm{s}}$ in $1^{\mathrm{m}}, 60^{\mathrm{m}}$ in $1^{\mathrm{h}}$, and $24^{\mathrm{h}}$ in a complete circle
- Sun at instant of Vernal Equinox is $0^{\mathrm{h}}$, 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 $21^{\text {st }}$ (365.25 day revolution)
- The Winter Solstice is the southernmost point the Sun reaches in the Celestial Sphere
- This occurs on December $21^{\text {st }}$ (365.25 day revolution)
- The angle of sunlight striking each location on earth varies with the movement of the Sun along the Ecliptic. The angle affects the concentration of heat/light striking the Earth
- When the Sun is in the northern hemisphere, the days are longer and more heat is delivered during the daylight, and when the sun is in the southern hemisphere the days are shorter and less heat is delivered during the daylight
- This is the cause for the 4 seasons we experience on most of the Earth
- The distance from the sun is not the cause of the seasons, but the angle the Sunlight strikes the Earth.
- The Earth is actually closest to the Sun in January and furthest in July
- There are two instances where the Ecliptic crosses the Celestial Equator
- Equinoxes are when there is exactly the same amount of day and night
- The Autumnal Equinox is when the Sun crosses from northern to southern hemisphere
- The Vernal Equinox is when the Sun crosses from southern to northern hemisphere
- Long-Term Changes
- The Earth revolves around the Sun every 365.242 solar days
- The Tropical Year is the amount of time it takes for the Sun to go from one Vernal Equinox to the next.
- This is the 365.25 days commonly referred to as a "year"
- Today we know the Earth's north pole also revolves around the Ecliptic North Pole
- Precession is the revolution of the north pole
- Due to the gravitational torque on the Earth by the Sun and Moon, the earth takes longer to revolve all the way back to the same position with respect to the stars than it does to revolve all the way back to the same position with respect to the sun
- This changes the direction the earth is facing each and every Vernal Equinox
- This means the Earth behaves just like a spinning top that is wobbling
- It also means that the "true north" of the Earth points at a different location in space each year. Every 13,000 years the "pole star" changes between Vega and Polaris.
- The Sidereal Year is the amount of time it takes for the Earth to go from a specific location relative to the stars back to the exact same location again
- The Sidereal Year is 20 minutes longer than the Tropical Year, which makes it every 365.256 Solar Days
- At this rate, it takes 26,000 years to complete one full precession


### 0.3 The Motion of the Moon

- Lunar Phases
- Unlike the reason for why the Sun moves in the sky, the reason the Moon moves in the sky is because it revolves around the Earth
- Phases are the different appearances of the moon as is revolves around the Earth
- There are 2 words that describe whether the Moon is getting lighter or darker
- Waxing is when the Moon is getting lighter each night
- Waning is when the Moon is getting darker each night
- There are 5 different words to describe the phase of the Moon
- New is when the Moon is completely dark
- Moon is directly between the Earth and Sun
- Crescent is when more of the Moon is dark than light
- Most of the lit part of the Moon faces away from Earth
- Quarter is when the Moon is $1 / 2$ Light and $1 / 2$ Dark
- Moon forms a $90^{\circ}$ angle with the Earth and Sun
" " 1 st Quarter" is used rather than "Waxing Quarter"
- " 3 rd Quarter" is used rather than "Waning Quarter"
- Gibbous is when more of the moon is light than dark
- Most of the lit part of the Moon faces toward the Earth
- Full is when the Moon is completely light
- Moon is on opposite side of the Earth as the Sun
- The Moon does not produce its own light, but reflects the light it gets from the Sun
- Its orbit does not lie in the plane of the Ecliptic, but at a $5.2^{\circ}$ angle with the Ecliptic which is what allows us to see the moon when it is full and see the sun when the moon is new despite one being between the other and the Sun
- The same face of the moon is always facing the Earth due to "synchronous rotation" which is when the rotation and revolution periods are identical
- The Sidereal Month is the amount of time it takes for the moon to go around the Earth and back to its starting point in the Celestial Sphere
- This happens every 27.3 days
- The Synodic Month is the amount of time it takes for the moon to go thru one complete cycle of phases from New Moon back to New Moon
- This happens every 29.5 days
- Because the Earth is also revolving around the Sun at the same time, it takes longer for the Moon to get back to the same position with respect to both the Earth and Sun
- Eclipses
- Every so often the Sun, Earth, and Moon will line up precisely and one object will cast a shadow onto the another object causing the $3^{\text {rd }}$ object to disappear from view
- This can only happen during a new or full Moon
- A Lunar Eclipse is when the Earth's shadow sweeps across a full Moon blocking the Sun's light from reaching the Moon
- During a Lunar Eclipse, the entire portion of earth that can see the Moon observes the same eclipse
- A Partial Eclipse is when only part of the object is eclipsed
- A Total Eclipse is when the entire object is eclipsed
- A Solar Eclipse is when the new Moon's shadow sweeps across the Earth blocking the Sun's light from reaching the Earth
- During a Solar Eclipse, there are different views seen from Earth due to the properties of light and the distance from the Moon to the Earth
- The Umbra is the darkest part of the shadow of the Moon where all of the light from the Sun is blocked
- The Penumbra is a lighter part of the shadow of the Moon where only some of the light from the Sun is blocked
- If the moon is not close enough to the Earth during the eclipse, no part of the Sun will be completely eclipsed as there is no part of the Umbra that reaches the surface of the earth
- An Annular Eclipse is when there is no Umbra on the Earth
- "Annular" comes from annulus which means "ring", which is what an Annular Eclipse looks like
- A ring of the sun can be seen along the outer edge of the moon in the sky


### 0.4 The Measurement of Distance

- Directions are important in Astronomy, but in order to make predictions or determine our exact place in the Universe, the distances are also needed to do calculations
- For centuries, humans have used their knowledge of Euclidian Geometry to calculate distances that were unable to be measured directly. This method is still used today in many professions.
- Triangulation is the method of constructing a Right-Triangle using 2 measurements along a known distance at the base of the triangle to calculate the distance to the object
- The Baseline is the name of the side in the triangle that is the known distance between the two locations being used to calculate the angle between them
- Using basic Trigonometry, all other parts of the triangle can be determined very accurately with just the knowledge of the angle between the two points along the baseline and the baseline itself
- The distance to the object and the angle along the baseline have an inverse relationship
- As the distance to the object increases, the angle will decrease
- 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

$$
\begin{gathered}
\frac{\text { Part of Small Circle }}{\text { Whole of Small Circle }}=\frac{\text { Distance on Large Circle }}{\text { Total Distance of Large Circle }} \\
\frac{2.7^{\circ}}{360^{\circ}}=\frac{\mathrm{km} \text { between towers }}{\mathrm{km} \text { around Earth }}
\end{gathered}
$$

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

### 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

