A Brief History of the Astronomy Basics

Its Origins & Celestial Motions

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Front Photo sourced from: (http://antwrp.gsfc.nasa.gov/apod/ap051220.html)

Goal:

Help teachers develop a meaningful and straight forward lesson for grades 9-12, specific to celestial navigation and motions.

1.) How to locate and predict motions of objects in the sky, orbit, and/or solar system.

2.) Interdisciplinary (historical, artistic, mathematic, and scientific).

Introduction

Overlying Background of Astronomy

The subject of astronomy has always been an interdisciplinary field, with a wide variety of research and topics that have been ever-changing and developing as time continues. Astronomy is one of the oldest of the natural sciences, if not the oldest itself, since a majority of the natural sciences can be explained through the varying aspects of research and phenomena that it presents (i.e. physics, mathematics, chemistry, geology, electromagnetism, gravitation, relativity, cosmology, meteorology, technologies, and many more). In fact, astronomy cannot be funneled into simply one single discipline at any one particular point in time. An understanding or communication of any one of its aspects deserves connections to its other relevant scientific fields, historical thinkers, and contributions that it has made; not only to the progress and development of other scientific fields, but to the advancements and level of understanding that we take for granted in today's world.

Background

Historical Progress of Astronomical Research

From our ancestors' understanding and observations of the sky above, they could predict the changing of the seasons and know the proper time to plant and harvest their crops. They used the predictability of the sky's motions to explain the regularly changing phenomena on Earth, and other marvels and wonders that they could not explain were attributed to their religious and spiritual beliefs as explanations to what they were seeing. Over time, this would lead to the understanding of the geocentric model, which was made popular by great minds such as Plato, Aristotle, and Ptolemy, and reinforced by the Church. This geocentric model (Ptolemaic Model) sought to explain the observed motions of the heavens as if the Earth was stationary, unmoving, and at the center of the universe. At the time, this was not a difficult conclusion to come to since the Sun, Moon, and starry host appeared to rotate around the physical Earth each and every day, and year after year. They believed that the Sun, Moon, and the observable planets (Mercury, Venus, Mars, Jupiter, and Saturn) were each on their own separate "spheres" nested around the whole Earth, with other spheres of objects and realms further beyond [see *Figure-1*] [1].

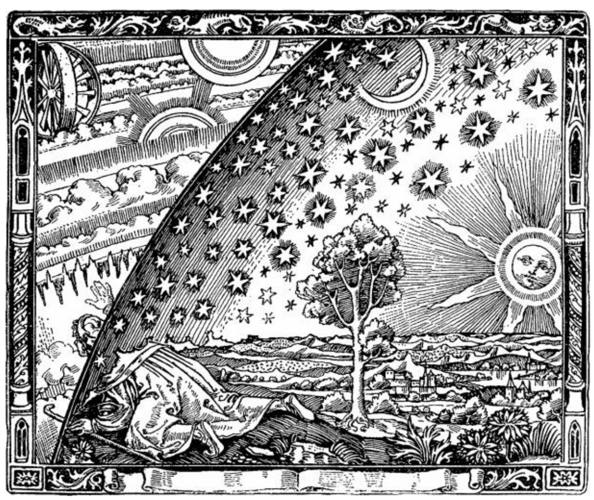

Figure 1: "Flammarion wood engraving"

[1] "Flammarion wood engraving" by an unknown artist, first depicted in Camille Flammarion's 1888 book "The Atmosphere: Popular Meteorology". Depicts a man at the edge of the Earth, peering beyond a layer of the firmament to reveal the layers of the universe further beyond.

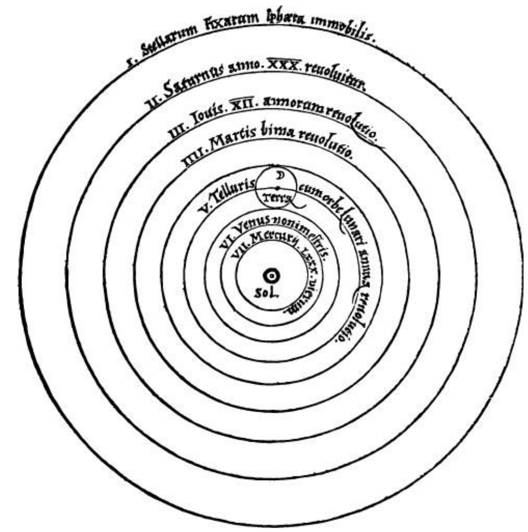

Figure 2: Heliocentric View of the Solar System

It wasn't until the Polish mathematician/astronomer Nicolaus Copernicus formulated a model of the universe and solar system [see *Figure-2* for the model] [2] with the Sun in its center (Heliocentrism) rather than the Earth in the center (Geocentrism) that our understanding of the celestial motions in the sky were drastically revisited, leading the way to the "Scientific Revolution". It should be noted, that while Nicolaus Copernicus was the individual who popularized the view of Heliocentrism, it was in fact Aristarchus of Samos that even Copernicus credited the sun-centered model of the universe nearly 1,700 years earlier [3].

Following Nicolaus Copernicus and his revitalization of the heliocentric model, the minds of Galileo Galilei, and Johannes Kepler with their accurate observations of planetary motion were soon to follow Copernicus' lead. Their observations and calculations of the celestial motions improved upon and eventually refined the heliocentric model, and although there were an increasing number of scientists in the era of the "Scientific Revolution", there were still individuals and groups who opposed the evidence of the heliocentric model in favor of the geocentric model, particularly the Church.

When Sir Isaac Newton came into the astronomical community, his contributions led to advancing telescopic mechanisms, calculus, his laws of motion, universal gravitation, and Newtonian mechanics. He provided an explanation of the planetary motions described and demonstrated by the heliocentric model in terms of gravity, and its effects on multiple celestial bodies. Newton used his mathematical resources and explanation of gravity to not only prove Kepler's laws of planetary motion, but also provide orbits for other solar system bodies, explain the tides, and many other gravitationally-explained marvels. His findings and proofs for gravitation would eventually lead to an overall acceptance and belief in the sun-centered heliocentric model of the solar system, but only years after his own death. It wasn't until 1822, nearly a century after Sir Isaac Newton's death, that the Church had approved a decree by *The Sacred Congregation of the Inquisition* that the printing of Earth-moving and heliocentric texts would be permitted [4].

By the middle of the 1800's, and leading into the latter part of the same century, advancements in photography began to take place, opening new windows of opportunity for scientific minds. The same time-period also hosted the births of Albert Einstein, born in 1879 Ulm Germany [5], and Edwin Hubble, born in 1889 Missouri of the United States [6]. Albert Einstein sought to advance upon Newtonian mechanics in favor of a more inclusive explanation to gravitation and electromagnetism, and by 1916 had published his theory of gravitation, which we know of today as General Relativity. Instead of gravity being an unseen force that would "pull" on celestial objects, as Newtonian mechanics seemed to suggest, Einstein had theorized that gravity was the "bending" or "warping" of our environment due to mass, which he referred to as the fabric of space-time. As early as 1919 during a total solar eclipse, his theory was confirmed with astrophotography of the eclipse, providing evidence

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[2] "Copernicus' System" *De Revolutionibus Orbium Coelestium (On the Revolution of Celestial Orbs)* 1543. Nicolai Copernici. 1st Edition

[3] George Kish (1978). *A Source Book in Geography*. Harvard University Press. P.51

[4] *Copernicus, Galileo, and the Church: The End of the Controversy* (1820), *Acts of the Holy Office* (Florence: Leo Olschki, 1992), pp. 300-301.

[5] Isaacson, Walter. *Einstein: His Life and Universe*. New York: Simon & Schuster (2007). P.11

[6] "*Biography of Edwin Hubble (1889-1953)*". NASA. Archived from the original on June 30, 2011. Retrieved June 21, 2011.

that the presence of a mass such as our Sun was enough to physically bend the fabric of space-time, causing background starlight to appear shifted from their true positions [see *Figure-3*] [7]. Throughout the 1920's, Edwin Hubble had begun publishing papers from his telescopic research and astrophotography that not only provided evidence that many of the nebulae that had been researched since the 1700th century were in fact entire galaxies, all existing beyond our own Milky Way galaxy, but also came to the discovery that galaxies were moving apart from one another, indicating an ever expanding universe [8].

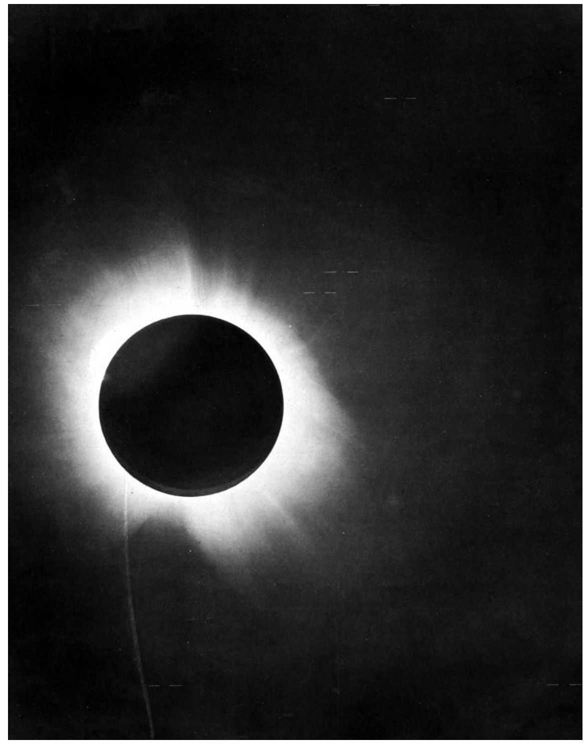

Figure 3: Photo of Albert Einstein's famous eclipse.

Much like Edwin Hubble's expanding universe, the science and discoveries that were made through the remainder of the 20th century accelerated beyond count, and it seemed that the world was experiencing a second revolution in science and technology. The 1900's not only had to react to Einstein's and Hubble's extraordinary findings with others as well, but also reacted to multiple World Wars, the dawn of the nuclear and atomic age, our current computer age, and even witnessed the invention of powered aircraft pave the way to humans setting foot on another world. We are now in the 21st century, and the number of inventions, discoveries, and advancements that are ahead of us are beyond count; new alloys, computing, propulsions, medicine, and countless more fields of research and science will all owe, even to a small degree, some credit to the great minds that began to describe the sky above them long ago… the astronomers.

The Earth's Many Motions

How the Earth Moves

The stars appear to rotate around the Earth each and every day seemingly unchanged, while the Sun, Moon, and other planetary bodies move more gradually and shift their positions over varying periods of time. All of these motions have similarities to one another, all defined through the same basic principles, but depending on the perspective of the observer those motions may appear to operate under different circumstances. This change in perspective can explain why the Earth's hemispheres experience opposite seasons, why the stars rise and set differently depending on where the viewer is on Earth, why the orbits of the inner planets appear different than the outer planets, and even how the stars change their position over long periods of time. We are, after all, on a planet with a moving geologic crust, rotating every day on a wobbling axis, orbiting the central star in our solar system, moving through the Milky Way galaxy, drifting through our Local Group of galaxies, and moving through an ever-expanding universe with countless other galactic clusters. When Galileo was being questioned and judged by the Church for his works on the planetary movements, with Galileo in favor of the current heliocentric model,

[7] F.W. Dyson, A.S. Eddington, and C. Davidson, *"A Determination of the Detection of Light by the Sun's Gravitational Field, from Observations Made at the Total Eclipse of May 29, 1919"* Philosophical Transactions of the Royal Society of London. Series A, Containing Papers of a Mathematical or Physical Character (1920): 291-333, on 332.

[8] Hubble, Edwin (1929). *"A Relation between Distance and Radial Velocity among Extra-Galactic Nebulae"*. Proceedings of the National Academy of Sciences of the United States of America. 15 (3): 168-173.

he was threatened with torture unless he recanted his beliefs of the Earth's many movements, after which he defiantly and famously muttered the phrase "*And yet it moves*" [9].

Motion Sickness

The sky's apparent motion is a direct reflection of the Earth's motion, most notably our daily rotation and yearly orbit around our Sun. To begin, let us first reflect on the axis that the Earth rotates on a daily basis. Go outside on any clear day or night, and you will notice that the Sun, Moon, and stars will rise in an easterly direction and set in a westerly direction. The sky that you are looking at, with all of its contents, appears to rotate around the Earth as if it were one solid structure. You should bring yourself to realize that this motion of the sky was one of the motions that defended the outdated geocentric model of the solar system. As our ancestors traveled the globe and continuously observed the sky, analyzed eclipses, the changing angle of shadows, and many other phenomena, they came to realize that the Earth we live on was spherical in shape [10] and one could eventually travel in a circle around the globe. The sky above, nicknamed the Celestial Sphere, appeared to move around the Earth, but they eventually determined that it was indeed the Earth itself that was rotating on a daily axis, making it "appear" that the sky was the object that was moving instead. Coincidently, even though we no longer recognize the geocentric model as the reason for our observations, we still refer to the sky and the coordinate system within it as the celestial sphere [see *Figure-4*] [11].

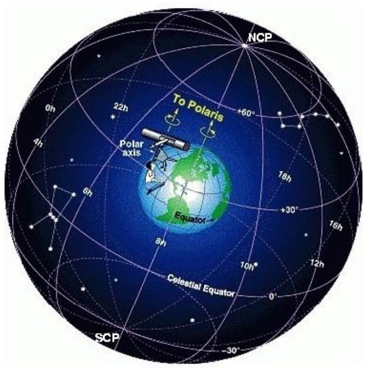

Figure 4: The Celestial Sphere

Depending on a viewer's location on the Earth's surface, specifically their geographic latitude, they will experience this rising and setting motion differently from someone elsewhere on the planet. For instance, a person on the Earth's equator will observe that the stars rise perfectly in the east, travel directly overhead, and eventually set in the west. Alternatively, a person located at either of the Earth's poles will observe that the stars appear to rotate in a complete circle around them and constantly over the horizon. And lastly, as is the case with a majority of the world's population, a person between the Earth's equator and polar axis will observe that the stars rise in the east at an angle, move in an arc across the sky, and set in the west at the same angle that they rose [see *Figures 5a, 5b, 5c* for images of the celestial sphere's movement] [12]. This motion of the sky, which takes

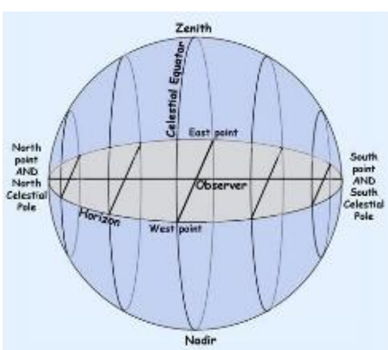

Figure 5a : Equatorial View

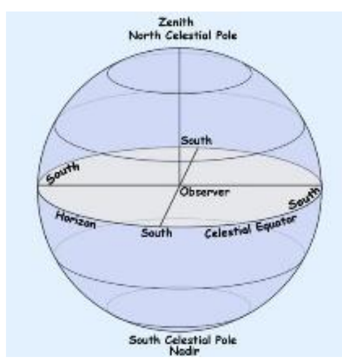

Figure 5b: Polar View

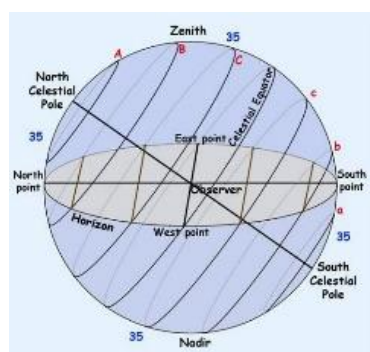

Figure 5c: Mid-latitude View

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[9] Drake, Stillman (1978). *Galileo at Work*. Chicago: University of Chicago Press

[10] The shape of the Earth and planets have a varying geometry to that of an "Oblate Spheroid". This is due to molten and gaseous interiors behaving as a fluid on a rotating axis, with a wider equatorial diameter than a polar diameter as a result.

[11] http://oneminuteastronomer.com/astro-course-day-2/

[12] http://cseligman.com/text/sky/motions.htm

about 23.9345 hours [13] to complete one rotation from west to east, slightly changes from one night to the next as the Earth continues to orbit around the Sun [see *Figures 6a, 6b, 6c* for photography representing the movements of the celestial sphere, accompanied with the images associated with Figure 5] [14].

Figure 6a: Equatorial View

Figure 6b: Polar View

Figure 6c: Mid-latitude View

The orbital direction of the Earth and all of the planets are the same counter-clockwise direction around our Sun. The Earth takes approximately 365.256 days [15] to complete one orbit of the Sun with respect to the background stars. An observer should notice that the year-length is slightly longer than a whole 365 days, which is one of the reasons why the Gregorian calendar incorporates a leap-year every four years, adding one additional day in the month of February at those times. There is one vitally important observation that even the ancients realized, before they were even completely aware of the heliocentric or geocentric models, and that would be the changing of the seasons. The temperature and the seasons got colder as the Sun would get lower on the horizon in the winter months, and would get warmer as the Sun would get higher on the horizon in the summer months. This changing of the seasons is entirely due to the axial tilt of the Earth, and depending on where the Earth is currently at in its orbit, one hemisphere is in a more direct line with the Sun for optimal heating while the opposite hemisphere has a more oblique line with the Sun for less heating [see *Figure-7*] [16]. The Earth's axis of rotation is

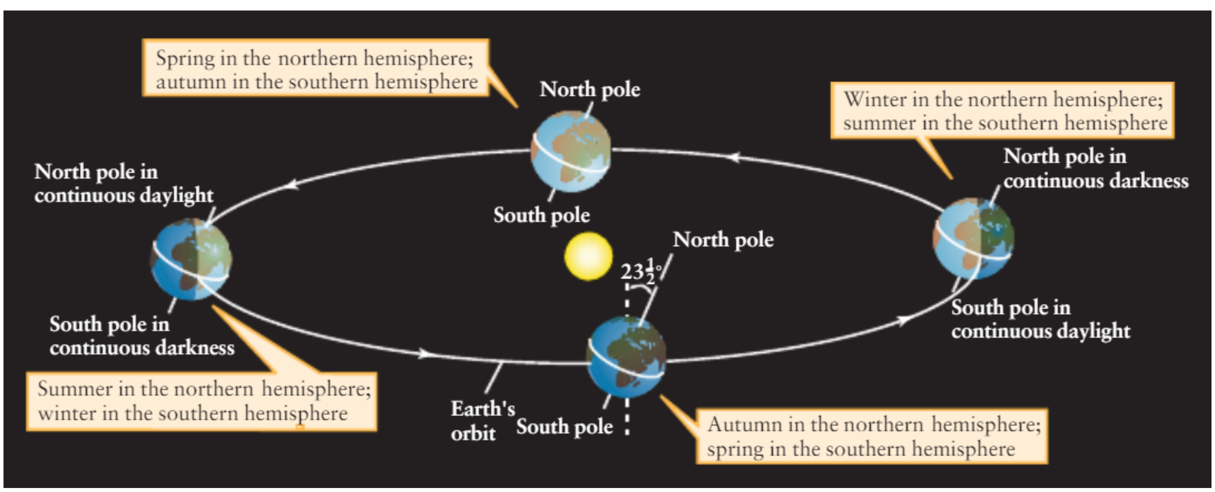

Figure 7: Seasonal changes with respect to orbital position.

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[13] Freedman, Roger A. and Kaufmann III, William J. (2008). *Universe: Eighth Edition*. New York: W.H. Freeman and Company

[14] Figure 6a: https://www.flickr.com/photos/aaronvonhagen/32363342531; Figure 6b: https://www.reddit.com/r/alaska/comments/82vg0a/attempted_star_trails_before_the_night_sky_is_gone/; Figure 6c: http://www.elcielodecanarias.com/galeria/trazas-estelares-orm/.

[15] Freedman, Roger A. and Kaufmann III, William J. (2008). *Universe: Eighth Edition*. New York: W.H. Freeman and Company

[16] Freedman, Roger A. and Kaufmann III, William J. (2008). *Universe: Eighth Edition*. New York: W.H. Freeman and Company

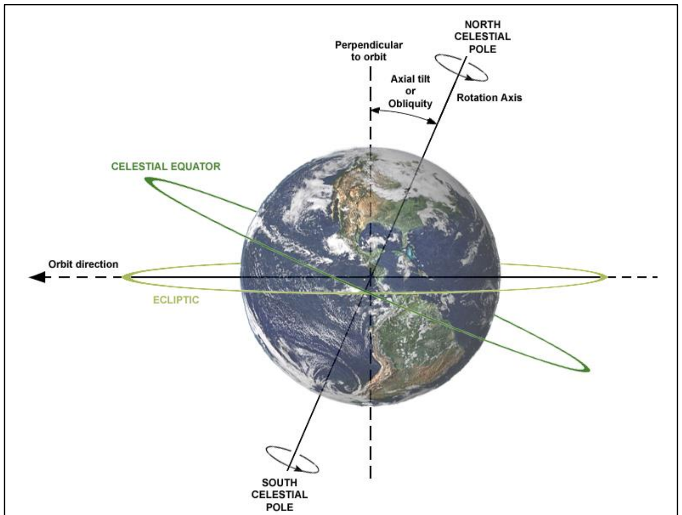

Figure 8: The 23.5° axial tilt, rotational axis, orbital plane, and the celestial equator.

tilted 23.5° from the perpendicular direction of its orbital plane, and maintains this orientation throughout a single year with the Earth's North Pole always pointing at the north celestial pole; that is, the northern pole and axis of rotation that the celestial sphere appears to rotate around [see *Figure-8*] [17]. Following along with Figure-7 and Figure-8 together will illustrate that whichever hemisphere is pointed more directly at the Sun is experiencing its summer, while the opposite hemisphere is experiencing its winter.

Since it is actually the tilt of the Earth's axis and its current position in its orbit that determine the seasonal changes on Earth, it is important to note at this time that the Earth does not experience its seasonal changes because of its proximity to the Sun, as some would believe. The tilt of the Earth allows for one hemisphere to always have more direct sunlight than the opposite hemisphere, providing a larger flux of energy to warm that side of the Earth's surface. This tilt is what creates the change of seasons, rather than the planet's proximity to the Sun which can vary throughout different times of the year since the Earth has an elliptical orbit [18]. The variation of the Earth's proximity to the Sun has a direct correlation to its other orbital dynamics, such as the orbital shape, area covered, and relationship between orbital time and distance. These principles are something that Johannes Kepler noticed, and can be demonstrated by looking into his three laws on planetary motion [see *Figure-9*] [19]. His three laws on planetary motion are as follows:

1.) *The Law of Orbits*: All planets move in elliptical orbits, with the Sun at one of the two foci.
2.) *The Law of Areas*: A line that connects a planet to the Sun sweeps out an equal area over equal times.
3.) *The Law of Periods*: The square of the period of any planet (years) is directly proportional to the cube of the semi-major axis of its orbit (Astronomical Units, AU).

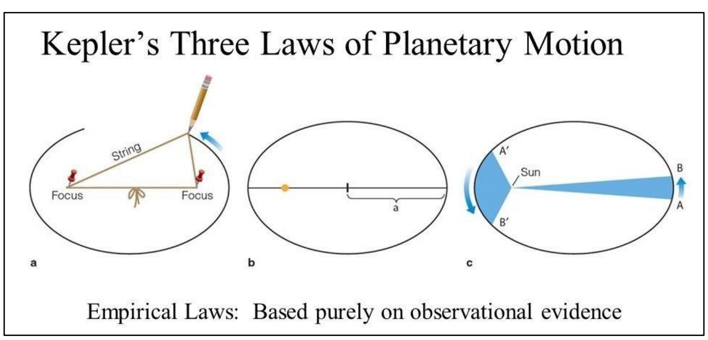

Figure 9: An illustrative representation of Kepler's laws.

[17] http://oneminuteastronomer.com/astro-course-day-2/

[18] No planet or orbiting celestial object has a perfect circular orbit, but varying degrees of an elliptical orbit with the main gravitational body located at one of the two foci of the ellipse.

[19] https://disqus.com/home/channel/atomsworld/discussion/channel-atomsworld/the_laws_of_science_part_1/newest/

The point in the year that is known as the Summer Solstice is when the Sun is at its highest point in the sky with respect to the Earth's axial tilt. Similarly, the Winter Solstice is when the Sun is at its lowest point in the sky, the Vernal Equinox is when the Sun crosses the celestial equator toward the northern hemisphere, and the Autumnal Equinox is when the Sun crosses the celestial equator toward the southern hemisphere. The Earth is actually closest to the Sun in the month of January, when the Earth is at a position called perihelion on its closest approach, and furthest from the Sun in the month of July when the Earth is in a position called aphelion on its farthest approach. When the Earth is closest to the Sun at perihelion, it is orbiting at a faster rate around the focus of its elliptical orbit, which is centered on the Sun. Then, as the Earth's orbital momentum slows and gets farther from the Sun in July at aphelion, it orbits at a much slower rate around the Sun. For any measured duration of time during Earth's orbit, the area that its orbital line sweeps out will be equal to that of any other area of its orbit under the same duration of time, which happens to be Kepler's 3rd Law.

From the viewpoint of Earth, if an observer were to track the position of the Sun over the course of an entire year, they would notice that it travels across the sky and against the background stars. However, because the Earth rotates very quickly and once in a 24 hour period, it may take an observer a little longer to notice the changing position of the Sun, which travels a complete circle across the background sky only once per year. As the Earth orbits our central star, our perspective of the background stars on the celestial sphere changes slightly throughout the year. Once we make a complete orbit around the Sun, our perspective of the celestial sphere will be the same as it was exactly one year before, and predictably the same one year from the present. It was this observation that led our ancestors to be able to predict what time of year they would have to observe different activities, such as the seasonal migrations of animals, planting and harvesting their crops, planning their festivals, and many more. After reflecting on these reoccurring changes in the sky, our ancestors began to name and describe various shapes and objects they could identify in the heavens, in order to tell a story and give reason to the changes they were experiencing on Earth. Even though the stars have slightly drifted over the ages, we still recognize many of those patterns and shapes in the sky, which are referred to as constellations.

Piecing it all Together

Connecting the Dots

A constellation is simply nothing more than a pattern of stars and the boundary that forms a perimeter around it, and that the stars and objects in a particular constellation are only "close" to each other by line-of-sight. Objects in a constellation can range from planetary bodies within our own solar system, stars separated by thousands of light years, to even galaxies separated by hundreds of thousands of light years. Just because celestial bodies may reside within the same constellation boundary, based from our Earthly perspective, does not mean that those celestial bodies are physically close together; in reality, those objects may be separated by sometimes fathomless distances [see *Figure-10*] [20].

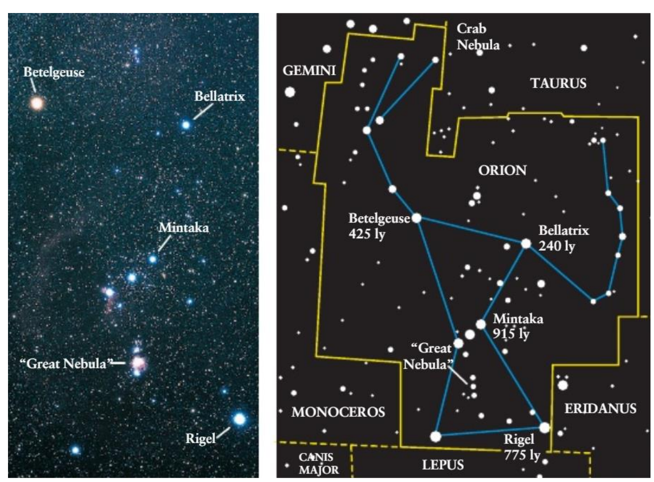

Figure 10: Representation of the Orion constellation shown in visible light (Left), with constellation lines/boundaries (Right).

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[20] Freedman, Roger A. and Kaufmann III, William J. (2008). *Universe: Eighth Edition*. New York: W.H. Freeman and Company

Today, we recognize that there are 88 different constellations on the celestial sphere. While trying to identify some of those constellations, it should quickly become obvious that the constellations are not all the same size. Some are extremely large and take up great areas of the sky, while others are very small and might be difficult to find for a beginning astronomer. Alternatively, some constellations are very well known and may be commonplace in speaking with other people, while other constellations might not be as well-known or popular. Even though there are many different constellations on the celestial sphere, an observer will not be able to see all of them at once, which will depend on the time of day and their physical latitude on the Earth's surface. However, for any astronomer or casual observer, it is extremely useful to navigate through the many objects in the night sky if at least a few landmark constellations are known to the viewer throughout the year. Being able to correctly locate a constellation or star-pattern from a star map is one of the first great steps an observer can take, since those identified constellations can assist the observer in further locating a different target in the future based on its proximity to the areas they have already identified. It is for reasons such as this, that entire expanses of the sky have been named according to the time of year they may easily be seen, which involve several constellations at once just to identify that area of the sky, such as the Summer Triangle, Winter Hexagon, Great Square of Pegasus, or the famous Big Dipper.

For anyone located in the northern hemisphere, being able to locate the bright stars of the Big Dipper is a great start to finding your way around the night sky, and can even be used to help you identify the north star, Polaris. Being able to find the star Polaris is not only a useful tool that an observer can have as they navigate the rest of the celestial sphere, but can also help identify a sense of direction for the viewer. Polaris can be used as a guiding star if you get lost in the wilderness or at sea, and can help you identify your geographic latitude and sense of direction on a map. It is also known as the North Star, or the Pole Star, since it will always be up in the sky for any observer in the northern hemisphere, pointing in the direction of north [21]. This northerly direction isn't just for your geographic direction on the Earth's surface, but also the northerly direction for the celestial sphere as well. By following along with Figure-11, you can locate two of the stars on the "bucket" of the Big Dipper and use them to point toward the next bright star, Polaris, which is the end-most star on the "handle" of the Little Dipper [see *Figure-11*] [22].

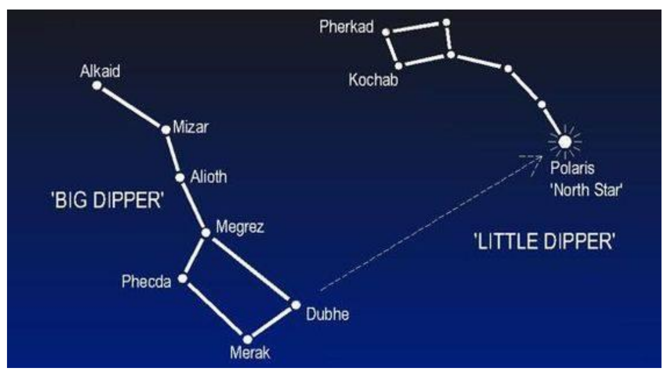

Figure 11: Depiction of how the pointer-stars of the Big Dipper can be used to locate the North Celestial Pole (Polaris).

Navigating the Sky

Finding Your Way

There are many different ways that astronomers find their way around the night sky, but most of them start with the same basic steps. Most observers prepare ahead of time before they go out to look at the stars, and this is

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[21] For any observers that are located on the North Pole of the Earth, the star Polaris will be directly overhead. For any observers that are located on the northern hemisphere but between the equator and the North Pole, the star Polaris will be the same degree of elevation above the horizon as your geographic latitude on the Earth's surface. For any observers that are on the Earth's equator, Polaris will be directly on the northern horizon. For any observers that are south of the equator, Polaris will not be visible.

[22] http://sjastronomy.ca/photographing-night-sky/putting-it-all-together/astrobybay-big-dipper-post2-1/

frequently based on the goal or task they have planned for the evening [23]. To use an amateur astronomer as an example, on a typical night they may choose to look at a celestial object in deep-space [24] with their telescope, and the following series of steps will roughly describe the process they go through.

They may first want to use any available texts, material, or computer software to determine ahead of time if the object they wish to see will be visible to them based on the date, time, their location, and the direction of the sky they wish to explore. If they can at least identify the constellation that the object is located in, they should already have a general idea of where they should be looking in the sky. Once they have verified that the object should be above the horizon and visible to them, they will gather any necessary equipment they wish to use over the course of the viewing and head outdoors. The astronomer will then find a suitable location to set up their equipment, making sure that the region of sky they wish to explore is free of any obstructions, such as lamp-posts, buildings, trees, and at least a certain elevation above the horizon to avoid blurry views through the telescope. Finding a suitable area for their equipment with a clear view of their target area of the sky, they will assemble their equipment and aim their telescope in the direction of the constellation that the deep-space object resides. If they are using a non-computerized telescope, they will need to use their telescope's small mounted finder-scope to further identify stars in the vicinity of the object they wish to find. This step in the process is usually accomplished by simultaneously looking at detailed star maps to verify the star-field around their object. When they feel they are close to finding the object in question, only very minor movements of the telescope are required as they "hunt" or search for the object through the telescope's main eyepiece. However, if the telescope they are using is computerized, they must first make sure that its settings and orientation are properly aligned with their GPS coordinates on the Earth's surface. The telescope's onboard computer will then prompt the astronomer to align the telescope, and there are generally a few different ways to accomplish this. Once they have properly identified and aligned the telescope with some stars or visible planets, the control panel will tell the astronomer that it is aligned and ready. The astronomer can then choose to search for the object's name in the computer's database (if it has a popular name), or simply enter the object's coordinates on the celestial sphere into the control panel. If the telescope's mount is motorized, then the entire apparatus will compensate for the rotation of the Earth over the course of the night, which means that the object will continue to be visible through the eyepiece without the astronomer having to move any other controls.

If an astronomer wishes to locate a celestial object very quickly, such as a constellation or star, and does not have any electronics or software available to them at the time, they may have a planisphere not far from their side. Usually accompanying an astronomer's texts and other star maps, a planisphere is a simple and easy-to-use tool for all ages, professions, and level of astronomy expertise. The planisphere is a highly recommended item to purchase [25] for anyone that wants to learn their way around the night sky, or simply be able to know what the sky will look like at any date and time. The function of planispheres are all the same, and the only difference generally found from one planisphere to another is the geographic latitude ranges that they are good for mapping. Generally composed of a front side and a back side, a planisphere has a star map that can be spun around a central

[23] The word "evening" is used loosely here, since astronomical research can technically be done any time of day in nearly any location.

[24] "Deep-space" is an umbrella term to generally categorize all celestial objects that are beyond our solar system.

[25] Planispheres make great astronomy gifts, and can be found at your local planetarium at an affordable price.

point with a visible year-round calendar around the entire perimeter of the map. Next to this calendar can be found several clock hours that can be aligned with the calendar dates. As a result, the easy operation of the tool can provide the viewer with a fairly accurate time-table of what constellations will be visible at a desired date or time; or reversely, if they know what the sky should look like at a particular moment, they can see what times of year those stars will fall exactly into that pattern [see *Figure-12*] [26].

Figure 12: Front side (northern direction) *Back side (southern direction)*

The Time-Keeping Coordinate System

The coordinate system that astronomers typically use is based off of the Cartesian coordinate system. However, the coordinates that are called out follow a very similar system to how we map geographic locations here on Earth. To locate an object here on the Earth's surface, we use a longitude and latitude coordinate system to locate a terrestrial object. The latitude is a measure of the angular position from the Earth's equator to either of the poles (north or south) and ranges anywhere from 0 degrees to 90 degrees. The longitude is a measure of the angular position from the Prime Meridian to either direction (east or west) and ranges anywhere from 0 degrees to 180 degrees. The coordinate system for the celestial sphere, however, has a few slight changes from this system.

To understand the coordinate system on the celestial sphere, it may be easiest to imagine that the Earth's latitude measurements are projected straight into the sky and onto the celestial sphere itself. For example, if an observer were to stand on the Earth's equator and look straight up they would define the celestial equator as being directly overhead, and an observer at the Earth's North Pole would define the celestial pole (+90°, or 90° North) as being directly overhead. By comparison, an observer at a geographic latitude of 35° North would look directly overhead and see stars at +35° (or 35° North). For the celestial sphere, the name of this coordinate direction is referred to as the Declination (Dec), and is usually preceded with a "±" to indicate if it is North (+) of the celestial equator, or South (-) of the celestial equator. For the 90 possible degrees that can be indicated in either direction, it can be further subdivided into "minutes" and "seconds", with 60 minutes being equivalent to one degree, and 60 seconds being equivalent to one minute. To demonstrate with an actual star, follow along

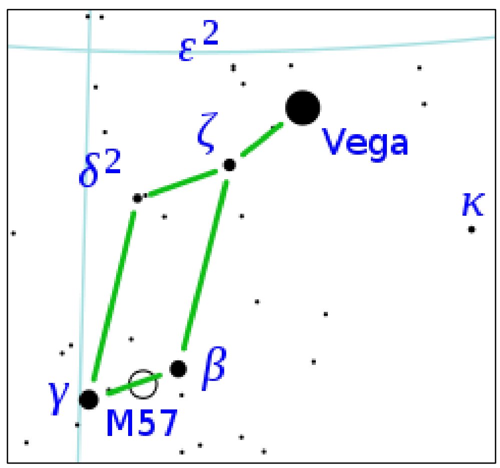


Figure 13: The bright star, Vega, in a segment of the constellation Lyra. Vega with epoch J2000 [RA: 18 ^{h} 36 ^{m} 56.33635 ^{s} / Dec: +38° 47' 01.2802"].

26 https://agenaastro.com/david-chandler-night-sky-planisphere-large.html

with Figure-13 that illustrates the star Vega [27] in the small constellation of Lyra. The declination coordinate for the star Vega can be represented in the form +38° 47' 01.2802" with an epoch [28] system of J2000. This means that someone at the same geographic latitude on Earth (such as Roseville, CA) will have the star Vega pass exactly over them once, for every day of the year.

The second coordinate frequently seen in astronomy is called the Right Ascension (RA), and for an experienced astronomer can be just as useful as knowing the time itself. The RA does not obey the Earth's longitudinal system, based off the Earth's Prime Meridian, but instead uses characteristics of the Earth's orbit to define specific points of right ascension. In the beginning of the spring season (March 20^{th}), the 23.5° tilt of the Earth's rotational axis allows for the Earth's equator (which is also the celestial equator on the celestial sphere) to align [29] with the orbital plane in which the Earth orbits the Sun, which is called the Ecliptic Plane (see Figure-8 again). This point on the celestial sphere is indicated as the starting point for the right ascension coordinate, and starts at 00^{h} 00^{m} 00^{s}. The right ascension can be read almost like a clock, represented with hour, minute, and second divisions [30] of the coordinate itself. Starting at 00^{h} 00^{m} 00^{s}, the coordinate progresses only in the eastward direction, until the system wraps around the entire sky and back to the beginning with a complete 24-hour naming scheme using the same hour, minute, and second subdivisions [see *Figure-14*] [31]. Using the star Vega as an example again [see *Figure-13* once more], its right ascension coordinate would be represented as 18^{h} 36^{m} 56.33635^{s} around the

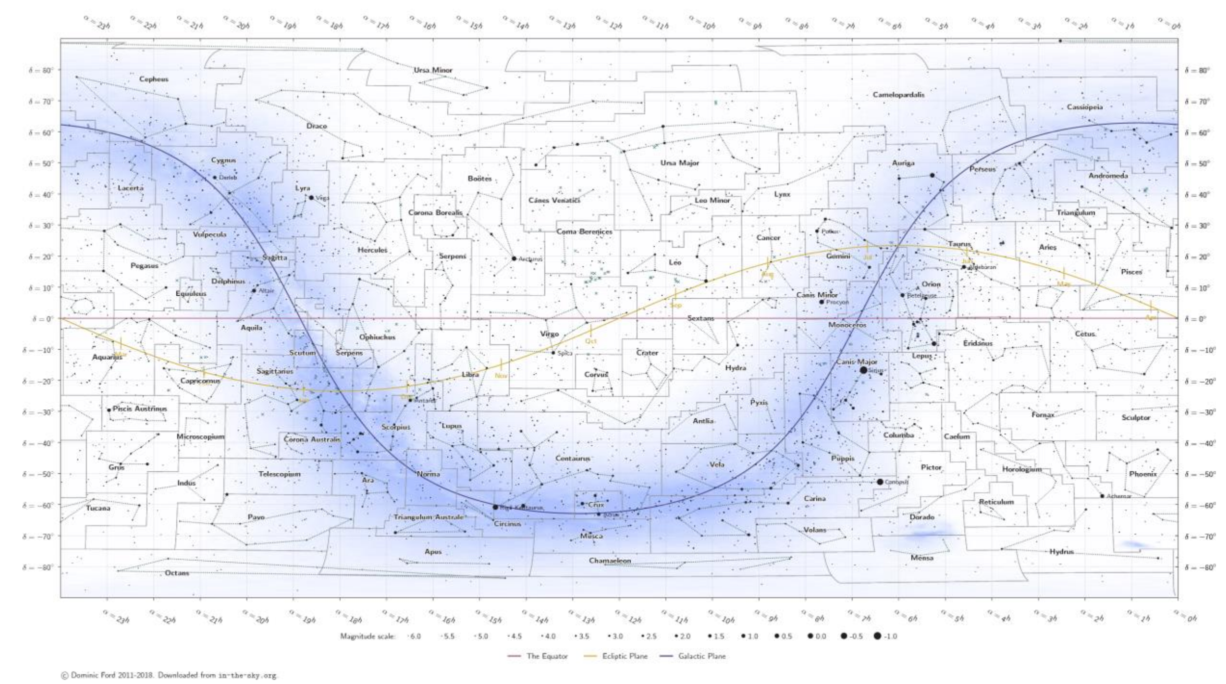


Figure 14: "Cylindrical map-projection" of the Celestial Sphere.

27 https://en.wikipedia.org/wiki/Vega

28 An epoch in astronomy indicates a specific reference of time. For systems using an epoch of J2000, those coordinates would simply mean that January 1, 2000 was the solid frame of reference for the coordinate system used, since the sky does in fact slightly vary and change over time. For current celestial coordinates, a system of JNOW will sometimes be used (accompanied with a date and time) to indicate the true position of the object at the specified date and time.

29 This particular alignment that occurs every year is known as the Vernal Equinox.

30 The terms "arcminute" or "arcsecond" may sometimes be seen when describing a celestial object's apparent angular size or degree of measurement between two or more objects.

31 https//in-the-sky.org/data/constellations_map

celestial sphere. Since there is no Prime Meridian on the celestial sphere like there is on the Earth's geographic coordinate system, the meridian takes a different form against the background stars. In the case of the celestial sphere, the meridian takes the form of an imaginary line that stretches from true north on the horizon, straight up [32] and directly over the observer, and finally down to the horizon at true south. This imaginary line figuratively cuts the observable sky in half, with current objects on the sphere either being west of that line or to the east of that line.

Even though star-maps may differ from the Earth's geographical maps by the naming and application of the coordinate systems they use, star-maps differ in at least one more extraordinary way. When a novice to astronomy first begins to use star-maps and attempt to locate stars on the celestial sphere, they soon realize that the directions of east and west are in opposite directions when compared to more familiar geographical maps. This can be described through one simple explanation, comparing the two mapping systems (geographic vs. celestial).

When looking at a geographical map with north at the top, south at the bottom, east to the right, and west to the left, this intended orientation affords the viewer a perspective of the map as if they were looking down, directly at the Earth itself. For proper orientation, the viewer may desire to have the north direction of the map (upper direction) physically point in the direction of true north. When looking at maps in this way, a map's compass directions can actually represent the directions on the physical terrain. Alternatively, a map of the celestial sphere operates under the same principle, except in reverse; the idea being that if the viewer were to hold the map over them, with north and south pointing in the proper and true directions, then they would see the east and west sides of the map point in their proper directions as well. Celestial star-maps are intended to be read as if the viewer were actually outside looking up at the star patterns.

Another coordinate system that astronomers may sometimes wish to use is the same navigating system that many other scientific and engineering disciplines often incorporate, and that is the altitude/azimuth coordinate system [33]. The altitude of an object is based off of its angular degree of elevation above [34] the horizon. That means that any object above a level horizon can only have values that range from 0° altitude to 90° altitude. The vertical direction that is above the observer (90° altitude) is commonly referred to as the zenith. If the direction of true north is accurately known to the viewer, they can measure out a complete 360° circle along the entire horizon until they return to true north again. Those coordinates rotate around the horizon in at counter-clockwise trend, so that the direction of east has a bearing of 90°, south has a bearing of 180°, west has a bearing of 270°, and then north returns to a bearing of 360°/0°. When using this method of coordinates in the practice of astronomy, there are few other pieces of information that are vitally important if the viewer is tracking a moving object (such as a satellite) or making any type of record-keeping of their observations. The viewer must first know their position on the Earth's surface, with the exact date and time that the altitude/azimuth coordinates were intended to represent. For example, if a news-channel network were to announce that the International Space Station (ISS) was going to travel over your local community on a given evening, an observer wishing to see the ISS fly overhead would need to know the exact time of the event and in what direction they should be looking for it. Similarly, if the observer were told the altitude/azimuth that they could find the object, they would still need to know the exact time for which they should be looking, in addition to an appropriate location that they may be able to view it from.

There is one tool that astronomers use to quickly and approximately identify measurements in the sky, and it is one that every potential viewer has on hand, quite literally. When stretching your hand out to arm's length, there

[32] For any observer outside, the "zenith" is the term used to denote the region of sky directly overhead.

[33] A common scientific profession, other than astronomy, that also uses this method are the geologic sciences.

[34] The horizon is interpreted as a level plane around the viewer, and negative values can also be present with this coordinate system (below the horizon), though this is not typically useful in astronomy.

are various regions of your own hand that can be used to approximate angles and measurements on the celestial sphere. At arm's length, the tip of your index finger can approximate 1° of measurement, the end, middle, and first knuckle can represent 3°, 4°, and 6° respectively, and the width of your palm can approximate 10° [see *Figure-15*] [35]. While this is not a precise way to accurately measure angular distances against the background stars, you can utilize your own hands to help you navigate from star to star, measure the tail-length of a falling meteor, approximate the dimensions or distances within a constellation, and many more.

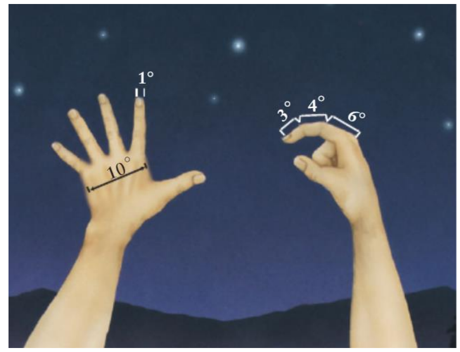


Figure 15: Approximate angular measurements that can done by hand.

Commonly Encountered Calculations

For crediting purposes, the following equations, figures, and mathematical problems were retrieved either in part or in whole from an instructive text [Freedman & Kaufmann III, 2008] [36]. The equations and workable problems are among those examples in the text that may frequently and casually be used by astronomers on a regular basis.

Small-Angle Formula: [Freedman & Kaufmann III, 2008; p.9-10]

Astronomers can use the small-angle formula to calculate an object's linear size (D), angular size in arcsec (α), or distance to the object (d), if at least two of the three limiting factors are known [follow along with *Figure-16*].

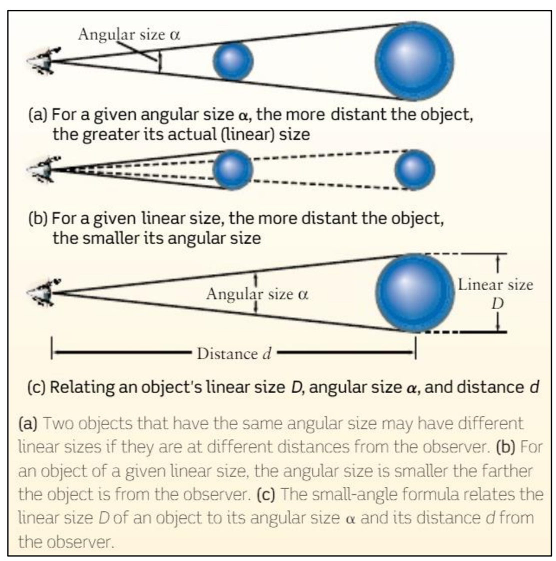
$$D = \frac{\alpha d}{206{,}265}$$

$D = linear\ size\ of\ an\ object$
$\alpha = angular\ size\ of\ the\ object, in\ arcseconds$
$d = distance\ to\ the\ object$

NOTE: The number 206,265 is required, and is equal to the number of arcseconds in a complete circle (360°) divided by the number 2π (the ratio of the circumference of a circle to that circle's radius).

Example: On December 11, 2006, Jupiter was 944 million kilometers from Earth and had an angular diameter of 31.2 arcseconds. From this information, calculate the actual diameter of Jupiter in kilometers.

$$D = \frac{31.2 * 944{,}000{,}000\ km}{206{,}265} = 143{,}000\ km$$



(a) Two objects that have the same angular size may have different linear sizes if they are at different distances from the observer. **(b)** For an object of a given linear size, the angular size is smaller the farther the object is from the observer. **(c)** The small-angle formula relates the linear size *D* of an object to its angular size α and its distance *d* from the observer.

Figure 16: Representation of angular size with respect to varying distances and sizes.

[35] Freedman, Roger A. and Kaufmann III, William J. (2008). *Universe: Eighth Edition*. New York: W.H. Freeman and Company
[36] https://www.scribd.com/doc/258110252/Universe-8th-Edition-by-Roger-A-Freedman-and-William-J-Kaufmann-III

Magnification: [Freedman & Kaufmann III, 2008; p.133]

The magnification of a telescope is equal to the focal length of the objective lens divided by the focal length of the eyepiece being used [follow along with *Figure-17* for the following two examples].

Example 1: A small refracting telescope has an objective lens of focal length 120 centimeters. If the eyepiece being used has a focal length of 4.0 centimeters, then what is the current magnification (x) of the telescope?

$$Magnification = \frac{Objective\ Focal\ Length}{Eyepiece\ Focal\ Length} = \frac{120\ cm}{4.0\ cm} = 30x\ greater$$

Example 2: Each of the two Keck telescopes on Mauna Kea in Hawaii uses a concave mirror 10 meters in diameter to bring starlight to a focus. How many times greater (x) is the light-gathering power of either Keck telescope compared to that of the human eye, if the dark-adapted pupil of a human eye is 5 millimeters? The light-gathering power is proportional to the square of the diameter.

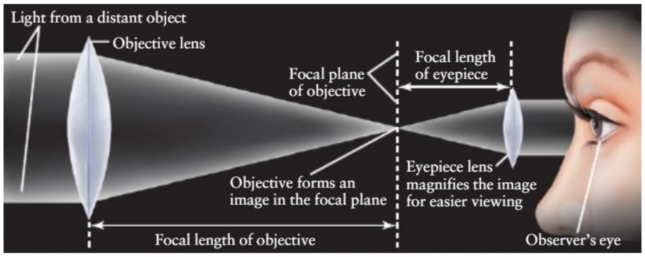


Figure 17: Illustration of crucial magnification elements.

$$(10\ m) * \left(\frac{1000\ mm}{1\ m}\right) = 10{,}000\ mm$$

$$\left(\frac{(10{,}000\ mm)^2}{(5\ mm)^2}\right) = (2000)^2 = 4x10^6 = 4{,}000{,}000x\ greater$$

Kepler's 3rd Law: [Freedman & Kaufmann III, 2008; p.76]

Kepler's third law relates the sidereal period (P) of an object orbiting the Sun to the semimajor axis (a) of its orbit. You must always keep two critical points in mind when using this relationship:

$$P^2 = a^3$$

1.) The period (P) must always be measured in years, and the semimajor axis (a) must always be measured in astronomical units (AU).
2.) This equation applies only to the special case of an object (such as a planet orbiting the Sun). If you wish to analyze the orbit of Earth's Moon, a spacecraft, or another planet around a distant star, then you must use a generalized form of Kepler's third law (Newton's form).

NOTE: An astronomical unit (AU) is effectively the mean distance between the Earth and the Sun. The Earth-Sun distance in astronomical units is given as the following (AU = 1).

Example 1: The average distance from Venus to the Sun is 0.72 AU, which is the semimajor axis (a) of the planet's orbit. Use this information to determine the sidereal period (P) of Venus.

$$P^2 = a^3 = (0.72)^3 = (0.72 * 0.72 * 0.72) = 0.373$$

$$P = \sqrt{P^2} = \sqrt{0.373} = 0.61\ years$$

Example 2: A small asteroid takes eight years (P) to complete one orbit around the Sun. Find the semimajor axis (*a*) of the asteroid's orbit.

$$a^3 = P^2 = 8^2 = 8 * 8 = 64$$

$$a = \sqrt[3]{a^3} = \sqrt[3]{64} = 4\ AU$$

Newton's Form of Kepler's 3rd Law: [Freedman & Kaufmann III, 2008; p.86]

Newton's form of Kepler's third law is much more general, and can be used in any situation where two objects with mass (m_1 and m_2) are in orbit with each other. This form is more applicable to a moon orbiting a planet or a satellite orbiting around another world.

$$P^2 = \left[\frac{4\pi^2}{G(m_1 + m_2)}\right] a^3$$

$$P = siderial\ period\ of\ orbit, in\ seconds$$
$$a = semimajor\ axis\ of\ orbit, in\ meters$$
$$m_1 = mass\ of\ first\ object, in\ kilograms$$
$$m_2 = mass\ of\ second\ object, in\ kilograms$$
$$G = universal\ constant\ of\ gravitation = 6.67x10^{-11}$$

Example: One of the Galilean moons of Jupiter, the moon "Io", orbits the planet at a distance of 421,600 kilometers from the center of Jupiter and has an orbital period of 1.77 days. Determine the combined mass of Jupiter and Io, after rewriting the equation to solve for the sum of their masses (m_1 + m_2) and converting all appropriate data into the correct units.

$$(m_1 + m_2) = \frac{4\pi^2 a^3}{GP^2}$$

$$a = (421{,}600\ kilometers) * \left(\frac{1000\ meters}{1\ kilometer}\right) = 4.216x10^8\ meters$$

$$P = (1.77\ days) * \left(\frac{86{,}400\ seconds}{1\ day}\right) = 1.529x10^5\ seconds$$

$$(m_1 + m_2) = \frac{4\pi^2 a^3}{GP^2} = \frac{4\pi^2 (4.216x10^8\ m)^3}{(6.67x10^{-11})(1.529x10^5\ s)^2} = 1.90x10^{27}\ kilograms$$

Your Present Resources

Astronomers have a large number of resources that they will typically use for a number of different purposes. In today's world, however, those available materials that can be used to expand your knowledge of the heavens are increasing at an incredible rate. You will soon find that you don't have to look very far before you can find useful texts, programs, planetariums, shows, and most importantly… your own backyard. All you have to do to expand your knowledge of the sky is simply go outside, look up, and reflect on what it is that you are seeing. Before you even realize it, you may become an astronomer yourself!

The following list includes a few online sources or programs that may be of use to a novice astronomer, teacher, student, or anyone willing to learn more about the sky above them in an educational and entertaining fashion:

1.) Astronomy software such as Starry Night, Stellarium, or downloadable apps on portable devices.
2.) https://www.unr.edu/planetarium
3.) https://www.nasa.gov/
4.) http://www.astronomy.com/
5.) https://www.space.com/
6.) https://www.heavens-above.com/
7.) https://in-the-sky.org/index.php
8.) https://theskylive.com/
9.) http://www.sky-map.org/
10.) https://eclipse.gsfc.nasa.gov/