Lecture 1

The Night Sky

1.1 Overview

This course will take place in the planetarium during the next six weeks. For the first lecture, we will go over the night sky as seen from the Earth, and talk about the patterns in the sky that are visible, how they change over time, and how the change their appearance when we move around on the Earth.

The two weeks following, we will move out into the Solar System and start exploring our neighboring planets. First we will cover the four inner terrestrial planets: the Earth, Mars, Venus, and Mercury. We will talk about specifics of their surfaces and atmospheres and compare their different geologies and activity. The next week, we will move into the outer solar system where we will focus on the four gas giant planets, their icy moons, and the host of other rocky and icy bodies and debris in the outer Solar System. This latter category includes comets in the Oort Cloud as well as the Kuiper Belt objects.

We finish the Solar System with a Lecture on the Sun, and how it generates its energy. In an important aside, we will also discuss the physical processes by which light is emitted and absorbed by atoms. This is critical for understanding how we learn about the properties of distant objects if we can only sample their light to study.

In Lecture 4, we will move out of the Solar System and talk about the Milky Way Galaxy, and its main building block, the stars. We'll look at their life histories, the places they are born in, how they die, and how the life cycle of stars connects them with the interstellar medium. We will also discuss the major components of the Milky Way, as well as a theory about its origins.

In the last week, we are going to go on a whirlwind of a lecture on the whole rest of the universe, including looking at all the different types of galaxies and galaxy morphologies that we observe, a look at galaxy clusters, and clusters of galaxy clusters which turn out to be some of the largest structures in the visible universe. We will conclude with the Big Bang, and examine just some of the observational evidence that supports it. We will finish with some very recent results from cosmology that give rather startling revelations.

This is an introductory astronomy class, and as such, there are no prerequisites of any kind. I won't suppose that you have had any previous astronomical knowledge before. This class should be understandable even if you've never taken a science or math class before in your life (or perhaps it's been a decade or more since the last time that you have). Of course that will make my job a little more difficult, and I will try to make everything as understandable as possible to the average layperson. We will be covering an enormous amount of material, and it will be impossible to do any one topic justice. However in the end, I hope that you will have a deeper appreciation about the astronomical wonders around us, and have a very broad, albeit somewhat shallow, level of understanding of our universe.

1.2 The Celestial Sphere and Daily Motions

Imagine going back in time thousands of years, before there was the Internet, or cell phones, or cable or broadcast TV, or movies, or radio, or even electricity. Even just a hundred years ago, it was much easier to see the night sky. Lighting at night wasn't ubiquitous as it is now; although you could have campfires or torches, they didn't cast their light over a very wide area. All you had to do to see the night sky was to step away from these small pools of illumination and the sky would just be there, its vast expanse above and all around you.

It is obvious to us even as young children that the Sun moves in the sky. It rises in the east, transits across the sky, and sets in the west. Without the distractions of modern day city life, it would be obvious quickly to us all that the night sky moves as well, in a very regular and distinct way. Although some stars rose and made great big arcs in the sky, other stars hardly moved at all. These instead made small circular motions about a single point in the heavens. And for a star that was exactly at that point, it appeared to be stationary throughout the night.

It would appear that everything in the sky wheeled about this single point, as if the stars and the Sun were attached to the surface of a giant globe or dome that surrounds the Earth. This globe, or **celestial sphere** appears to spin about an axis. For nearly everyone in the Northern Hemisphere, one point of this axis is visible and is called the **north celestial pole**; and for people living in the Southern Hemisphere, they saw the opposite end of the axis of the spinning celestial sphere, and that is the **south celestial pole**.

Luckily for people in the Northern Hemisphere, there was a star that was almost exactly at the north celestial pole, and that is **Polaris**, the Pole Star. Thus throughout the night and throughout the year, Polaris will always be up in the night sky, and for most people living in the Northern Hemisphere, it was always located north of them. As a result, Polaris is also called the **North Star** and has been used for millenia as a navigator's tool in finding true North.

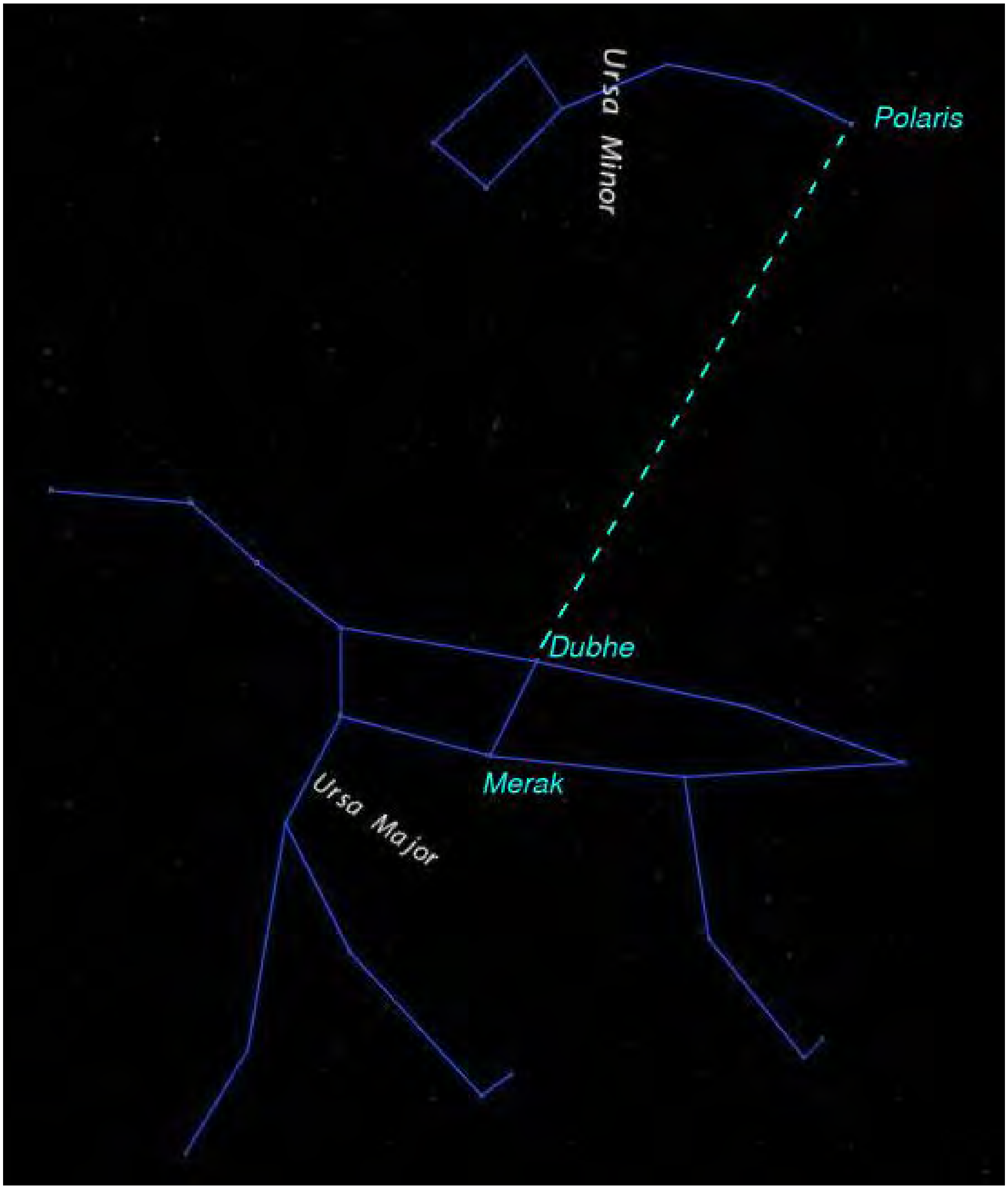


Figure 1.1: Finding Polaris

After locating the Big Dipper (or Ursa Major), draw a line between the two Pointer Stars, Dubhe and Merak, and follow it to the North Star, Polaris.

When we turn on the Cosmic Atlas calendar tool, we see that the time and date we have set for ourselves is sometime tonight[1]. Now as we move time forward quicker, the stars will rise in the east (to our left) and set in the west (to our right) faster. The stars further to the south (ahead of us) move in great big arcs as they rise and set; however the stars to the north, behind us, move in much smaller arcs. As you look closer to Polaris, the stars appear to move in circular motions with the circles centered about Polaris.

As we learn about the night sky, Polaris is a useful starting point since that is always visible every night throughout the year. However it is a somewhat faint star and it is hard to see. Luckily there is another set of stars that we can use to help us find Polaris. This is the **Big Dipper** which is also visible for most of the night for people living in the Northern Hemisphere. The Big Dipper is easy enough to make out as a constellation, and is bright enough that almost everyone can find it in the sky. When you go home tonight, see if you can find it (if it is visible and not covered by clouds).

After you locate the Big Dipper, look for the two bright stars that make up the far edge of the bowl in the Dipper. These two stars are the two brightest stars in the Big Dipper, **Dubhe** and **Merak**. They are also called the **Pointer Stars** because if you connect them with a line and follow it above the Big Dipper, you will hit Polaris. After you find Polaris, which sits at the end of the handle of the **Little Dipper**, you will be able to trace out the rest of its parent constellation.

1.2.1 The Autumn Sky

We will be able to proceed to find other constellations once we have located these first two. Notice that the Little Dipper appears upside down to us in the fall months. One American Indian myth explains that the autumn colors spill out of the Little Dipper when it is upside down, and that is what makes the leaves on trees turn colors in the fall.

Now let us follow the Pointer Stars past Polaris an equal distance away and you will find a set of stars shaped like a W. This is **Cassiopeia**, named after the Queen of the Ethiopians in Greek mythology. To the west of her is a set of fainter stars that are shaped like a house with a peaked roof. This is her husband, **Cepheus**. On the other side of Cassiopeia is the constellation of **Andromeda** which is made up of two trails of stars that form a big curved V in the sky. And just off to the side of the V of Andromeda is a fuzzy patch of sky, which is where the Great Galaxy in Andromeda is located. We will discuss galaxies at the very end of this course, but you should remember that if you are able to see the Andromeda Galaxy, you are looking at the farthest object that can be seen by the naked eye without the aid of binoculars

[1]The reason why the hour and date seems to be off is that it is currently using Greenwich mean time, or time as recorded at the Greenwich Observatory outside of London. Since London is 6 hours ahead of us, if you subtract 6 hours from the time shown, it is roughly the time now.

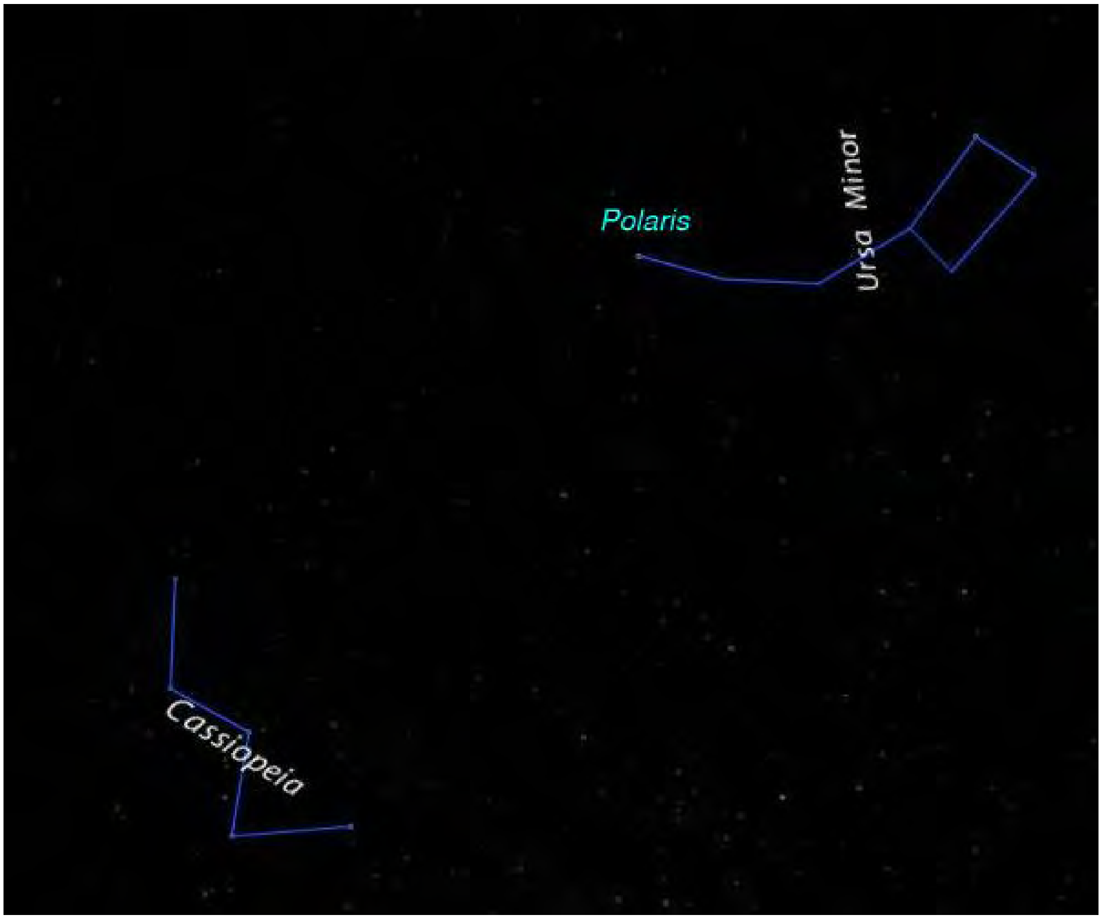


Figure 1.2: Cassiopeia
Roughly the same distance on the other side of Polaris from the Big Dipper is the constellation of Cassiopeia.

or telescopes[2]. In the east, and roughly north of Cassiopeia and Andromeda, is the constellation of **Perseus**, which has a trapezoidal body, and arms and legs sticking out. If we go back to Andromeda, we see that the tip of the letter V is the star Alpheratz which is also part of the constellation of **Pegasus**, the flying horse. The rest of Pegasus is made of a large square, of which **Alpheratz** makes up one corner. The Great Square of Pegasus is especially easy to see because the stars that make up its corners are bright, and only very faint stars are found inside the square.

Already we have enough constellations to tell a story. If you remember your Greek mythology (or perhaps you have seen the movie *Clash of the Titans*), Cassiopeia, the queen of Ethiopia claimed that she was more beautiful than the sea nymphs, the

[2]The Andromeda Galaxy is located roughly 1.5 million **light year**s away, meaning light from it has taken 1.5 million years to travel to our eyes.

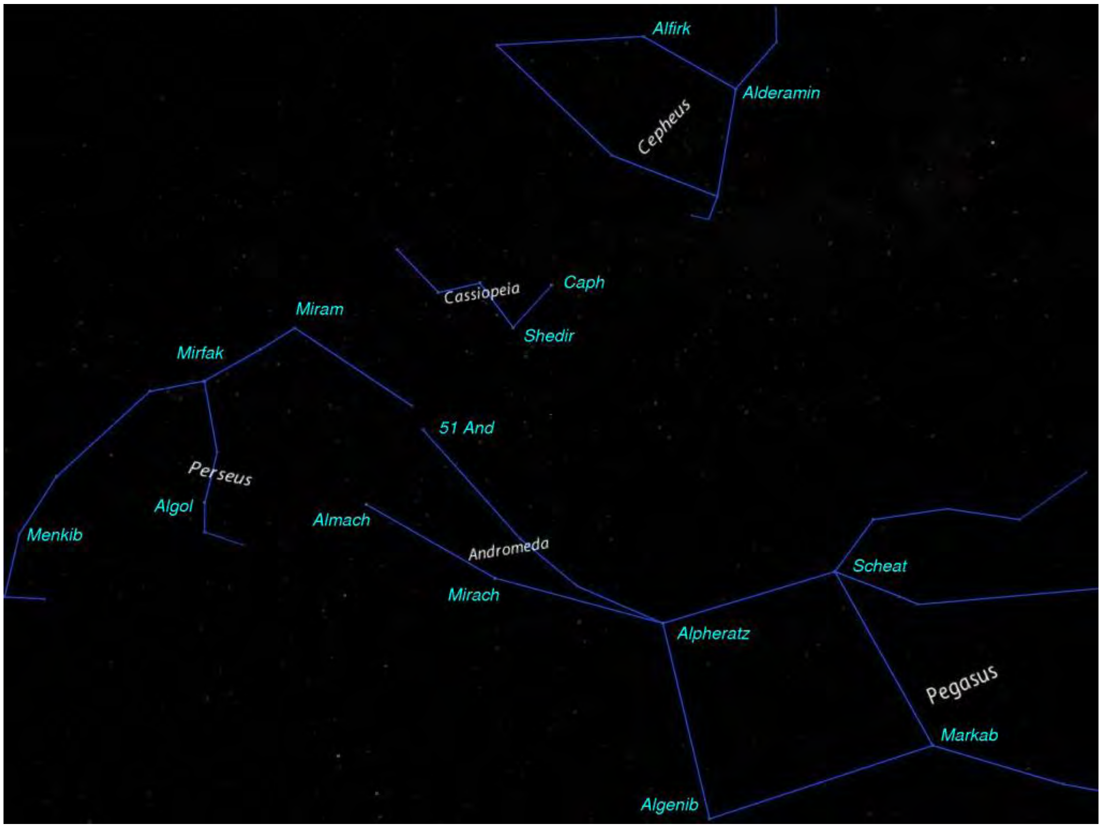


Figure 1.3: Cassiopeia, Cepheus Perseus, Andromeda, and Pegasus

Nereids. This greatly angered the sea nymphs, who complained to their father, the god Poseidon. (In Greek mythology, gods and goddesses were easily insulted, and many stories in Greek myth have the heroes trying to deal with the consequences of their anger). As punishment, Cassiopeia was forced to sacrifice her daughter Andromeda by chaining her to rocks by the coast, where she would be devoured by the sea monster Cetus. However Perseus was traveling through the region, saw Andromeda imprisoned against the sea cliff and fell in love with her. Perseus bargained with her parents that he would receive her hand in marriage if he could defeat the monster. On a previous adventure, he had slain the creature Medusa, who you might recall had slithering snakes instead of hair, and whose gaze was horrific enough to turn to stone anyone who looked upon her. Perseus had cut off Medusa's head, and he turned the decapitated head to Cetus, who immediately solidified into rock. Now Pegasus the flying horse is not in the original story at all, but the filmmakers behind *Clash of the Titans* also managed to work him into the script. In addition to the constellations that we have just covered, in Perseus, you will also find the star **Algol**, which comes from the Arabic for "The Ghoul." This star is often associated with the head of Medusa in that constellation.

1.2.2 The Winter Sky

For people in the northern hemisphere, probably the single most recognizable constellation after the Big Dipper is that of **Orion**, the Hunter. Orion is distinguished by three bright **Belt Stars**, the bright red giant star Betelgeuse at its left shoulder, the bright blue star Rigel at its right knee, **Orion's Sword** that hangs down from the Belt Stars, and the recognizable shape of a person usually viewed with one arm extended outward, and the other arm raised. Orion fell in love with the goddess of the hunt, Artemis. The god Apollo did not want his sister to fall for this mortal, so he sent a giant Scorpion to chase after Orion, who jumped into the ocean to escape its sting. Apollo then tricked Artemis into shooting an arrow into the sea, where Orion was hidden, and thus accidentally killing him. She tried to have the physician Aesclepius save Orion, but he was not able to do so. In the end, she had Orion placed up in the stars. The Scorpion was also transfered into the sky as the constellation of **Scorpio**. Scorpio is on the other side of the sky, so that Orion rises when Scorpio sets and Orion fades from view when Scorpio appears. So even today, the Scorpion continues its chase of the Hunter.

To the southeast of Orion is the brightest star in the sky, Sirius. Sirius is the brightest star in the constellation of Canis Major, the big dog, and hence is also referred to as alpha Canis Major. In sky lore, this constellation is usually referred to as one of Orion's hunting dogs. Sirius was especially important to the Egyptians since its first appearance in the morning sky marked the flooding of the Nile and the beginning of the Egyptian calendar (see § 1.4). Because this occurs in the summer months (today in late June, but for Egypt 3000 years ago, it occurred in early July), Sirius was thought to contribute to heating the Earth, and making the summers hot. Thus our expression "the dog days of summer" actually has an astronomical connection to the Dog Star.

Directly below Orion is Lepus, the Hare, which some accounts claim was placed in the sky for Orion to hunt.

To the west of Orion is Taurus the Bull which is most visible by the stars that make up its long pair of horns. The face or head of the bull is represented by a V-shaped cluster of stars with the bright red **Aldebaran** usually representing the eye of the bull in pictures. The constellation has been identified with a number of different possible bovines, but a story that is very common today is its association with Zeus. The king of the gods fell in love with the Phoenician princess Europa, and he turned into a gentle, white bull to get close to her. Zeus then carried her off, crossing the Mediterranean to get to Crete, where he revealed himself to her. There Europa became the first queen of Crete, and had three sons by Zeus, including Minos, the future king of Crete. This story also provides a mythical answer to why Cretan culture regarded the bull so highly.

The middle of the V contains a cluster of stars, the Hyades, that is easily seen in binoculars. Above the back of the Bull are the **Pleiades**, the Seven Sisters, probably the most famous and most easily seen cluster of stars in the sky. The Hyades and the Pleiades were each a group of seven daughters of the titan Atlas (by different mothers). The Japanese term for the Pleiades is Subaru, and if you look closely at the next Subaru vehicle that you pass by, you will find that the car company uses the stars in its logo.

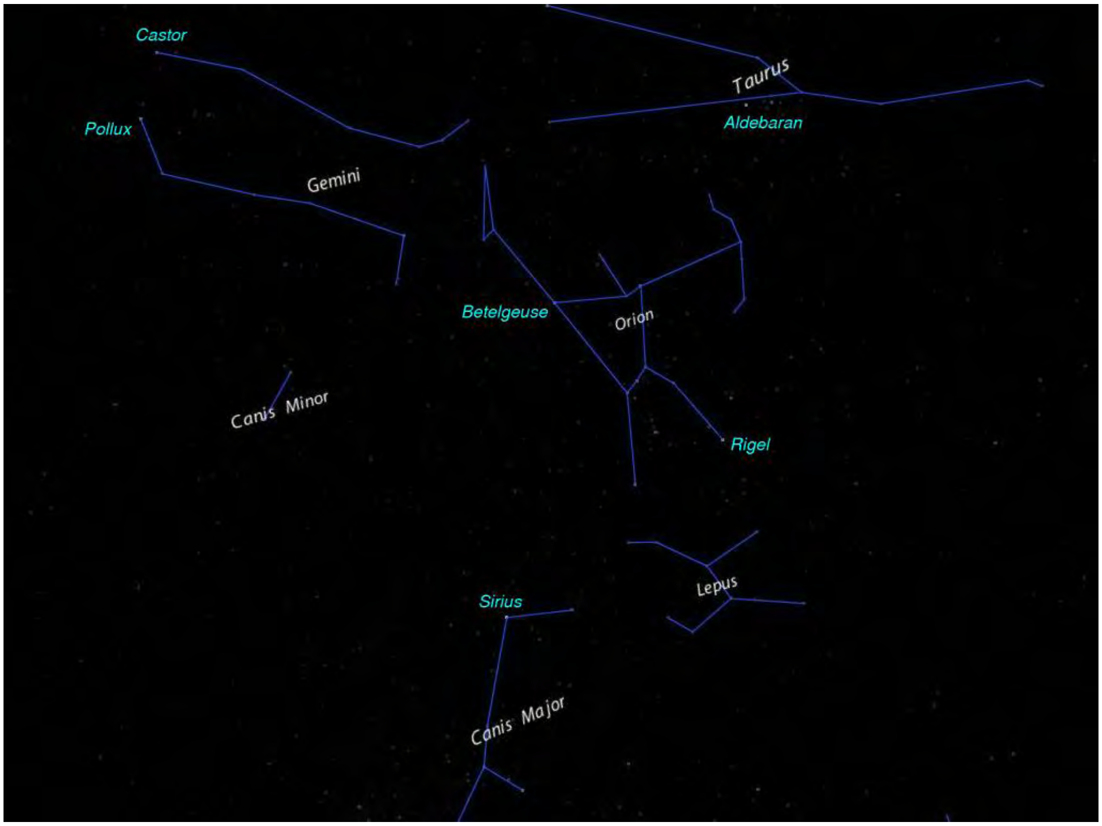


Figure 1.4: The Winter Sky

To the northeast of Orion are **Gemini**, the Twins, anchored by the two bright stars, **Castor** and **Pollux** (with Castor being the most northern twin). Both were the sons of Leda, who was seduced by Zeus after he turned into a swan to get close to her. Castor was the son of Zeus which made him immortal. The two brothers were extremely close and had many adventures together. Their last one was as members of the Argonauts, who with Jason were on the campaign for the Golden Fleece. Pollux was killed during the quest, and Castor became inconsolable from the loss, and petitioned his father so that he could die as well. Zeus was touched by this act of filial love and placed both brothers in the sky.

To the south of Gemini is the star **Procyon**, part of **Canis Minor**, the Lesser of Orion's two hunting dogs.

Further to the east of Gemini is **Cancer**, which consists of faint stars so is very difficult to see from any location with light pollution. The constellation is usually marked by four stars, with one inside the triangle formed by the first three.

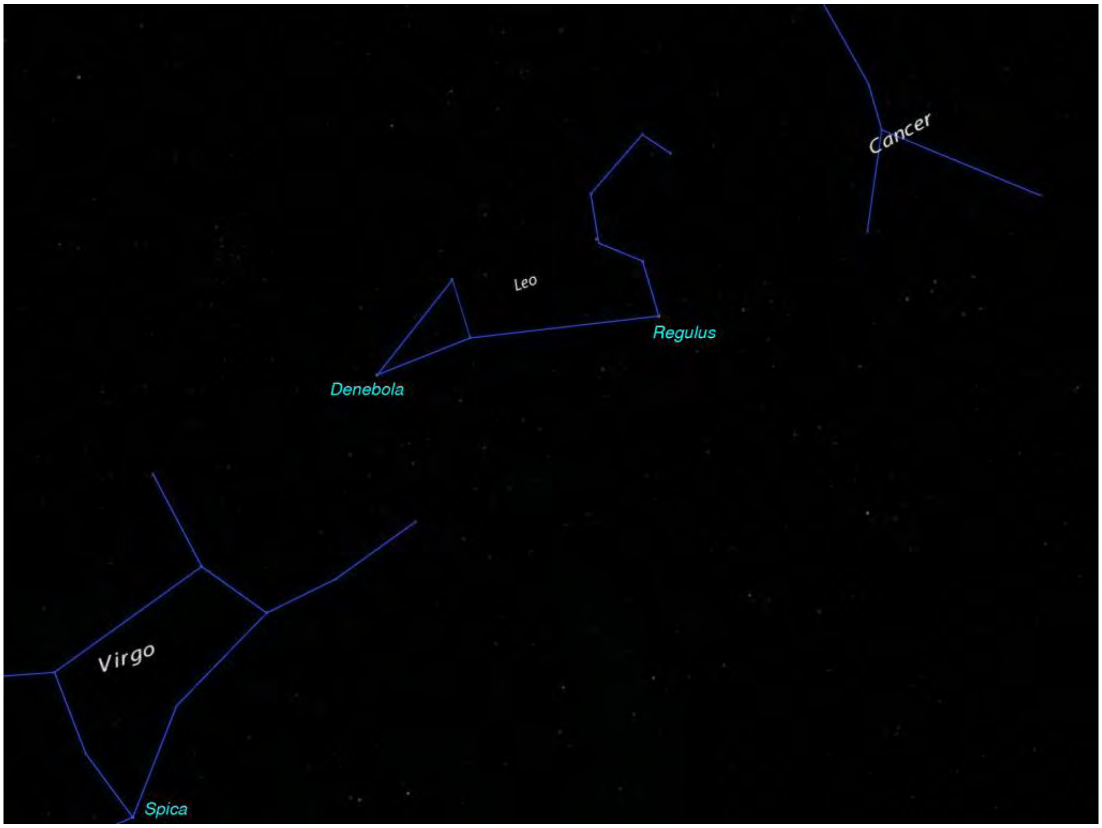


Figure 1.5: The Winter Sky: Leo and Cancer

In late winter, it is easy to find **Leo** the Lion, up in the night sky without having to stay up too late. The shape of a reclining lion, with a maned head is easy to imagine from the bright stars of the constellation. **Regulus** is its brightest star and is located at its front paw; the second brightest is **Denebola**, literally meaning the *Lion's Tail* from the Arabic.

Now form a line between Denebola (at the tail of Leo) and the star **Zozma** at Leo's back near where his rear leg should be. Extend this down to the southeast and it will connect with **Spica**, at the southernmost edge of **Virgo**, the next constellation in the zodiac past Leo. Virgo is a large, sprawling, and dim (except for Spica) constellation, usually depicted as a figure of a woman, oriented sideways in our sky, with her head closest to the Lion.

1.2.3 The Spring Sky

Start at Ursa Major, the Big Dipper, which should be high in the early evening sky. Find the end of the Dipper and follow the arc of the handle until you "arc" over to **Arcturus**, the brightest star in the constellation of **Boötes**. Boötes is easy to identify for modern day skygazers because the constellation is shaped like a giant ice cream cone, with Arcturus located at the tip of the cone. Boötes is usually identified as the Herdsman in the sky, watching over his oxen—not Taurus the Bull, which is halfway across the sky, but the oxen pulling the wagon or wain that is associated with the Big Dipper by many northern European peoples. However Boötes has also been called the "Bear Watcher," by those cultures that saw a bear in that grouping of stars. In fact the name of its brightest star, Arcturus, has been applied to the constellation as a whole, and comes from the ancient Greek words for "Bear Guard."

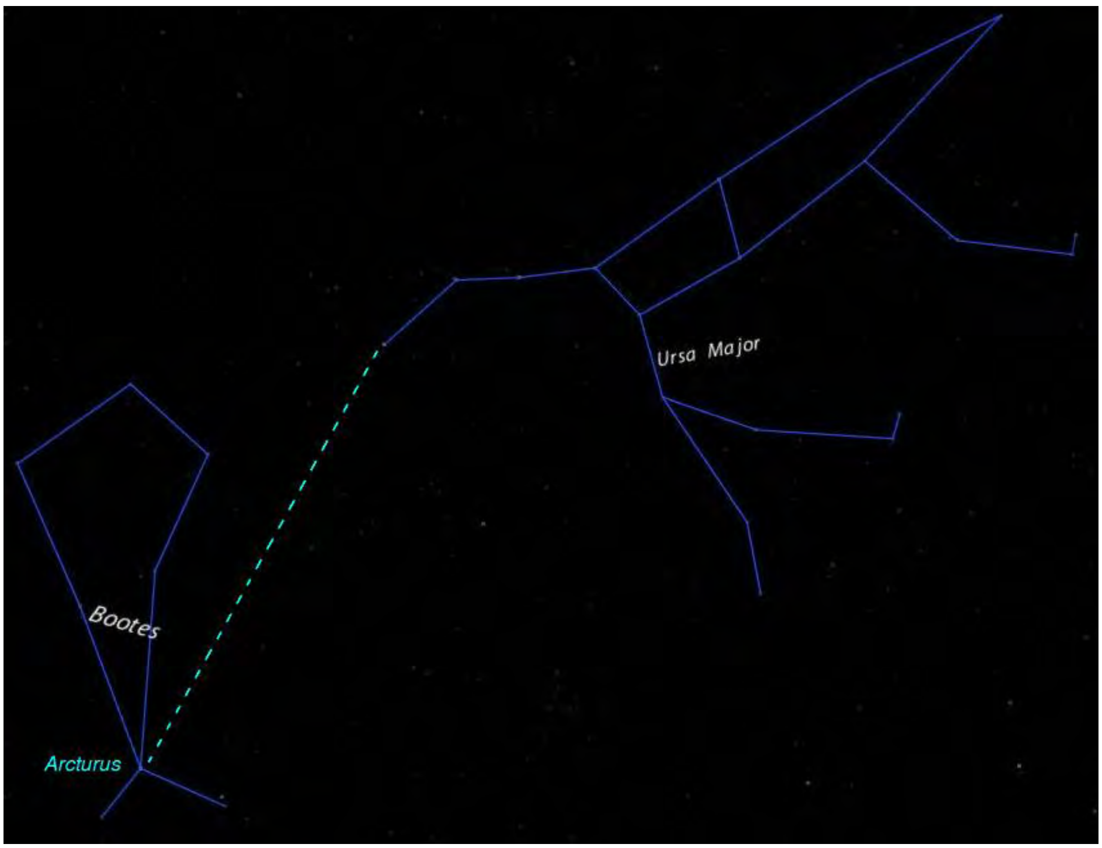


Figure 1.6: Arcing to Arcturus
"Arc" to Arcturus by following the handle of the Big Dipper to the bright star Spica.

In the southern sky, look for the bright red star **Antares**, which is in the eye or head of **Scorpio**, who chases after Orion the Hunter. The Scorpion's tail arches down and to the east away from Antares, and is also easy to spot. However it is located just above the southern horizon from Denver so if there is sufficient light pollution to the south, you might miss it. The claws of the scorpion extend westward and join up with stars that make up **Libra**, the Scales.

Figure 1.7: Scorpio

1.2.4 The Summer Sky

The summer sky is dominated by three bright stars that form the **Summer Triangle**. They are **Vega**, **Deneb**, and **Altair**. Vega is the brightest of the three, and is located in the small constellation of **Lyra**, the Lyre. Deneb can be found in the enormous northern cross that makes up **Cygnus**. Recall that *Denebola* was the Tail of the Lion. Here, Deneb is the tail of the Swan, with its head at the end of a long neck on the opposite side, and the wings extending outward to form the arms of the cross. Altair is the eye of the Eagle, **Aquila**. The body of the bird lies to the south of that star, with the wings extending (appropriately enough) spread-eagled to the sides.

Toward the southern horizon, and to the west of Scorpio, is another easy-to-spot constellation. **Sagittarius**, the Archer, has the appearance of a large teapot that includes a spout (on the west end), a handle (to the east), and a cover (to the north). Sagittarius is important to astronomers because it is in its direction where the center of our Galaxy can be found (something that will be taken up in Lecture 5).

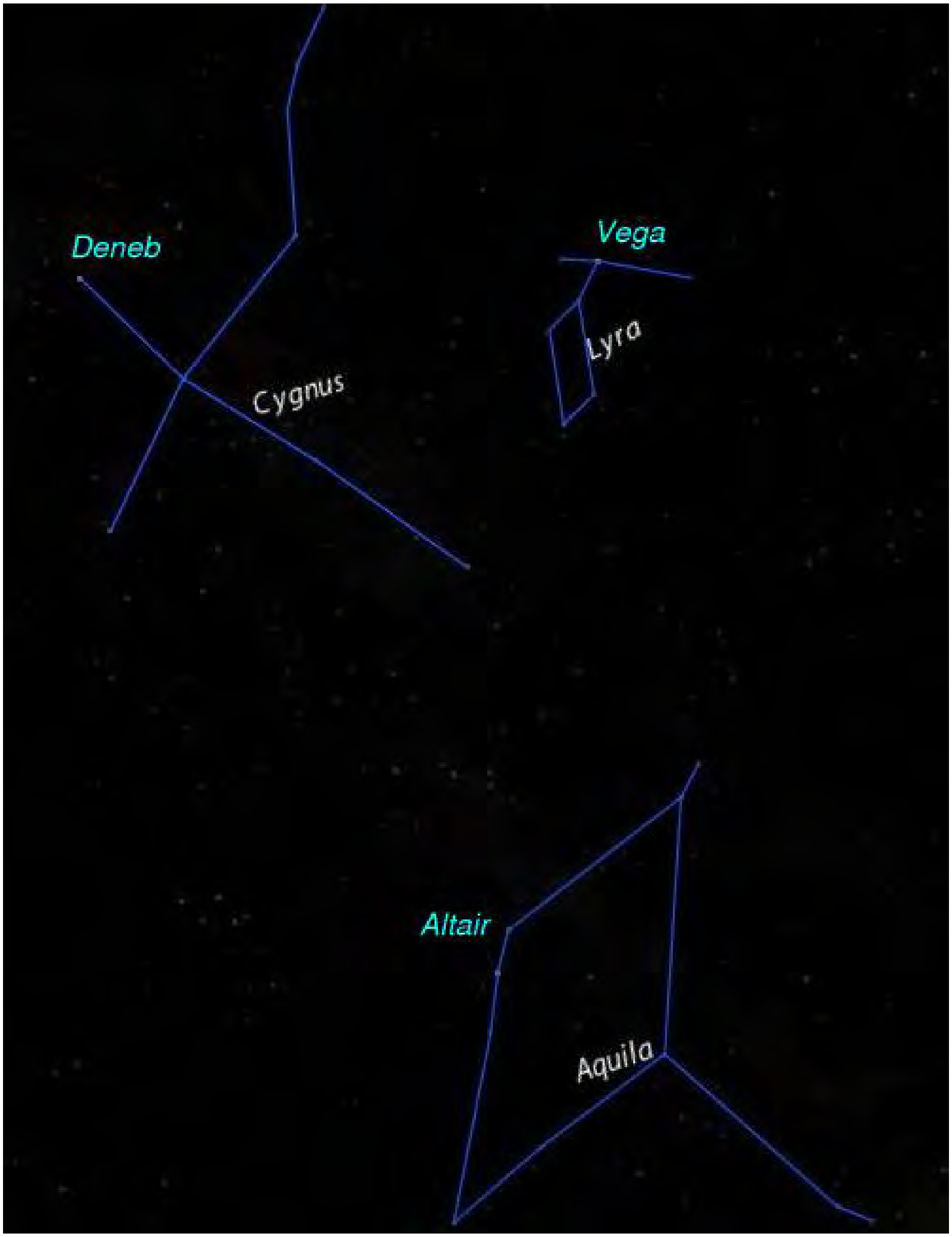


Figure 1.8: The Summer Triangle

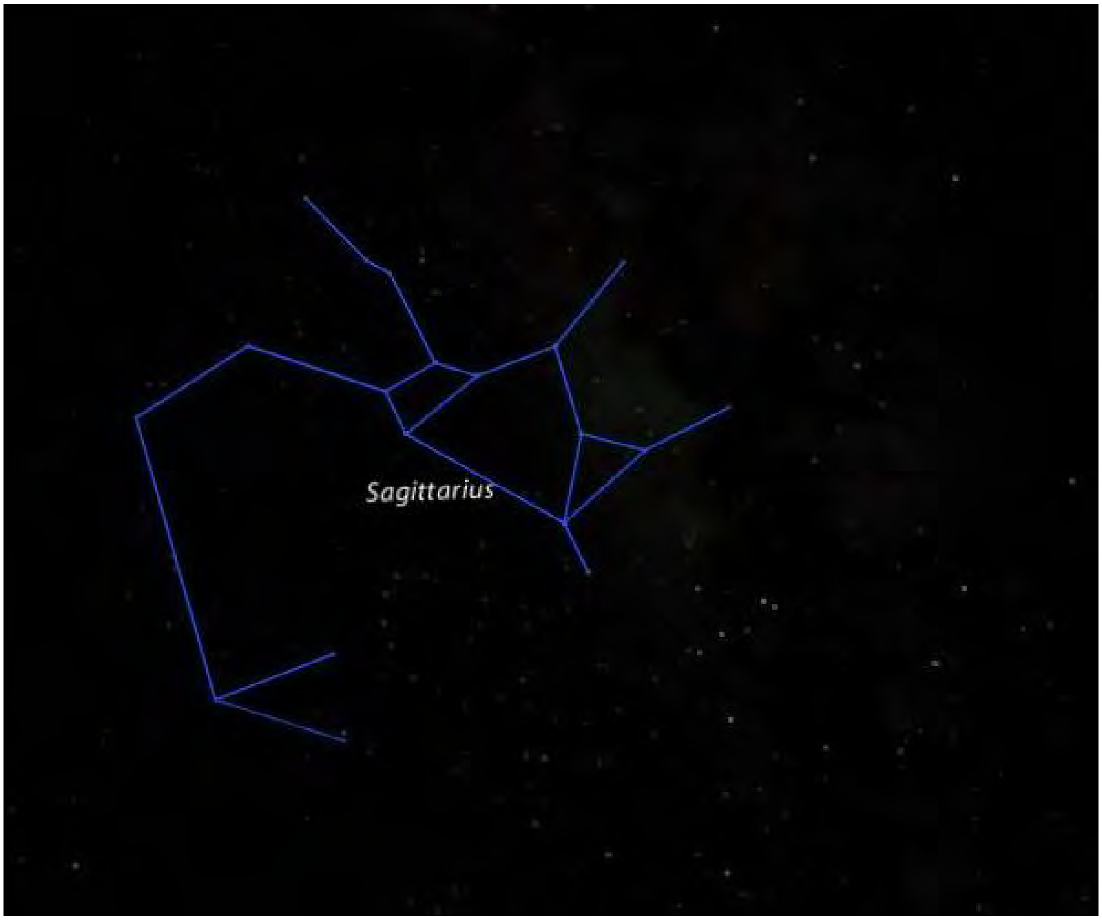


Figure 1.9: Sagittarius

As some of the previous accounts show, constellations can be very useful for learning about the stars. You can assign constellations characters from your culture's myth or other stories that you can easily remember. Although many of our constellations are named after figures in Greek mythology, the Big Dipper, also known as **Ursa Major** or the Great Bear, was identified as such in many cultures throughout Europe, Asia, and North America. To connect us to the Museum's current exhibit, *Quest for Immortality*, this is true even for the ancient Egyptians, which is an curious fact because bears were never found that far south. As a result some astronomers have suggested that the bear identification originated in Eurasia during the Ice Ages and was disseminated by various peoples through the millenia as they migrated and spread out to different continents. And although the Greek myths are prominent in today's accepted identifications of constellations, do not think that other cultures haven't played a role. Our zodiacal constellations originate from the civilizations in the Near East; for instance 5000 years ago, Leo and Taurus made frequent appearances in

Mesopotamian artifacts.

1.3 The Stars from Different Latitudes

We have discussed how the night sky and the constellations appear to us here in Denver. What if we were to go to Minneapolis instead? The stars would so that Polaris would be higher up in the sky, closer to the **zenith**, the direction directly above our heads.

If we were to move further north say to Anchorage, Alaska (at a latitude of 61°), we see Polaris shift even more. At this location, the motions of the stars trace more complete circles in the sky. Only stars furthest to the south have incomplete arcs.

Similarly if we physically travel south toward the equator, the North Star will move lower in the sky toward the northern horizon. In this planetarium, Polaris will move beyond the edge of the back of the visible dome. The majority of the stars now clearly rise from the east and set in the west.

How can we explain what is going on in the sky given our modern day knowledge of the Earth? Luckily we all know today that the Earth is not flat, but is spherical, giving us a leg up on the ancients who did not have this knowledge. We also know that the Earth rotates on an axis; that the intersection of this axis on the surface is geographically labeled as the **north pole** and **south pole**, and the great circle line equidistant between the two is the **equator**. The Earth can be further divided into lines that mark increasing **latitude**s north and south of the equator, as well as **longitude** lines east and west of some arbitrary point[3]. The reason why the stars appear to rise and set in our sky is not because they are fixed to the sky, and that is rotating above us. Instead, the Earth is rotating underneath the fixed stars.

We can visualize this more clearly if we take the north and south poles of the Earth, as well as its equator, and extend them outward until they connect with the celestial sphere of the sky. *These intersection points mark the celestial north and south poles, as well as the celestial equator.*

If you have ever sat on a train, and it starts to slowly move in the forward direction, it will seem to you that the world is moving in the opposite, backward direction. This will be the case especially if the motion is so slow that you don't feel yourself moving. Similarly, as the Earth rotates on its axis during the course of a day, to us sitting stationary on the ground, the sky will appear to turn in the opposite direction.

A spherical Earth spinning on its axis also explains our different views of the heavens as we move in latitude. When we are further south, closer to the Earth's equator, the celestial equator will be high in the sky, and the celestial North Pole (and hence Polaris) will be further toward our northern horizon. The stars will tend

[3]This arbitrary **meridian** line of 0° longitude is defined in modern times to run through Greenwich, England. By our modern convention of how the Earth is subdivided, the geographic coordinates of Denver is roughly 105° West, and 40° North.

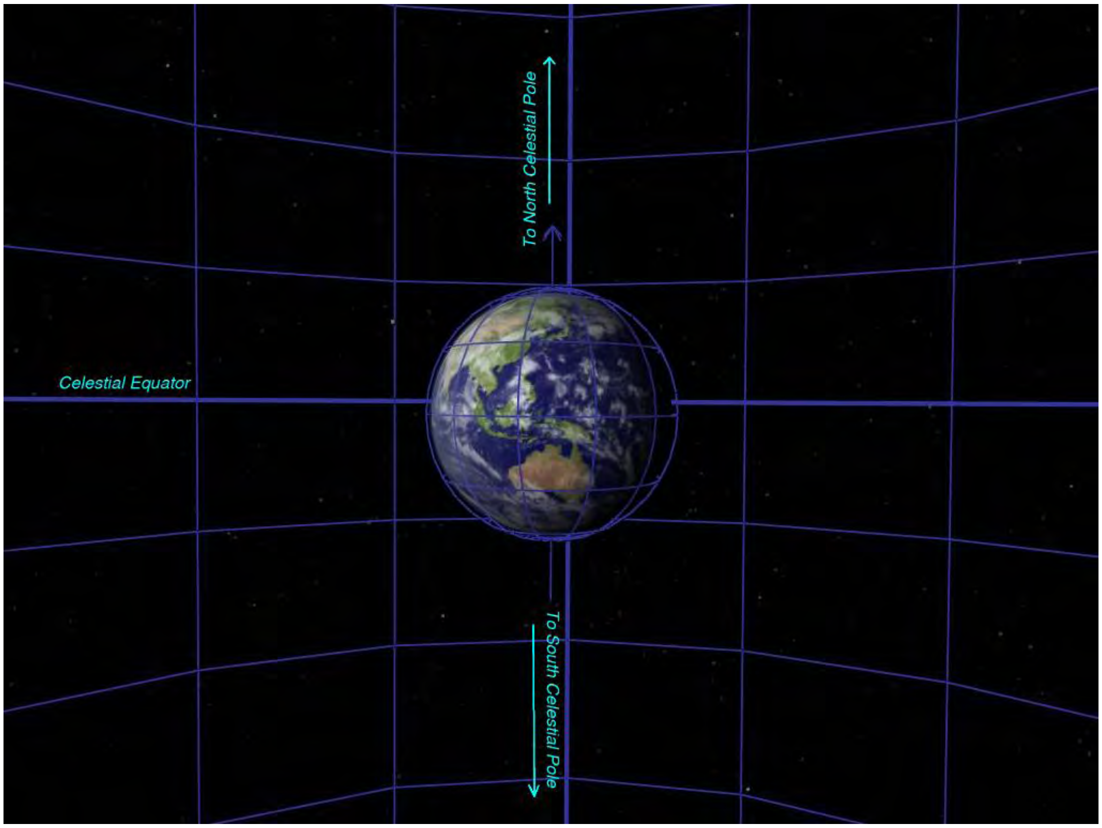


Figure 1.10: The Celestial Equator and Celestial Poles
Extend the Earth's equator and poles out into infinity, and where they intersect the celestial sphere are the celestial equator *and* celestial poles*.*

to more clearly rise, arc, and set.

If we transport ourselves on the Earth to the northern latitudes, Polaris will move higher up in our sky. The celestial equator moves down toward the horizon; and the stars now move in large horizontal arcs between rise and set. If instead of watching the stars, we watch the Sun, we also understand why during summers at high latitudes near the Arctic (or Antarctic) circle or above, the Sun can stay up in the sky for so long. Instead of rising and setting overhead us, it skirts along the horizon, dragging out the length of the day.

1.4 Star Motions Through the Year

We have seen what constellations appear in particular seasons. Over the course of a year, some of the constellations disappear and new ones appear. This is because from day to day, any given star rises and sets slightly earlier each night.

Let's say you observe a star in the eastern horizon that is just barely visible in the glow of the rising Sun. On the day before, the star will have risen just a few minutes later, and hence the sky will be too bright for the star to be seen. On the day after, the star will rise a few minutes earlier and will be in the sky a few minutes longer before the Sun rises.

Figure 1.11: September Night Sky
A northern hemisphere person looking out into the night side in September (standing on the back side of the Earth shown here) will see constellations like Pegasus and Andromeda high in the sky.

If you compare the daily motions of the Sun with the daily motions of the stars, they are *not exactly the same!* Whereas the Sun takes 24 hours (a *solar day*) to make one complete circuit around our sky—say from noon to the next noon—the stars actually take slightly less time, about 23 hours 56 minutes (or a *sidereal day*) instead.

The day on which a star is first visible in the eastern sky right before dawn is called the day of **heliacal rising**. Similarly the day on which a star is first visible in the western sky right after the setting Sun is known as the as the day of **heliacal setting**[4]. Stars will appear in the sky at such heliacal rising and settings at exactly the same date every year. This is an important date-keeping tool for those without access to clocks or calendars. Ancient peoples used such appearances to tell them what date it was, within an accuracy of a day or two. Again to bring this back to

[4]The word *heliacal* means "near the Sun."

Figure 1.12: September Day Sky
At the same time of the year, the Sun will appear to be in the constellation of Virgo.

Quest for Immortality, the heliacal rising of Sirius, the brightest star in the sky, was used to begin the Egyptian calendar, since this marked the annual flooding of the Nile. Still other peoples used other stars to mark the beginnings in their calendar, or the start of the growing season; this has included the Belt Stars of Orion, and the Pleiades which have been important for Australian aborigines as well as for some Native American tribes.

Because of this difference between the daily motion of the stars and the Sun, if you watch the night sky over time, say over many weeks and months, you will see different constellations come into view. How do we explain what is going on given our modern day knowledge of astronomy? In addition to the Earth turning on its axis, we also know that it revolves in an orbit around the Sun, and the time for it to make one complete circuit is one year, or $365\,{}^{1}/_{4}$ days.

During the month of September, the Earth is in a position in its orbit so that at roughly midnight, a person will see Pegasus and Andromeda high up in the sky; if we were to look in the other direction (and if we could see the stars amid the glare of the Sun), we would see the Sun in the constellation of Virgo.

Over time, the Earth moves in its orbit. So if we were to wait a few months, and check the sky at Christmas, the Sun would be in the constellation of Sagittarius. At night, we would see a completely different set of constellations up in the midnight sky, including Gemini, Cancer, and Orion.

The small four minute difference between a star finding itself back in the same position in the sky versus the Sun getting back in its original position is directly related to the Earth moving in its orbit. Each day, the Earth moves a little bit further in its orbit. It is enough that the Earth has to rotate an extra four minutes before a person on the Earth can see the Sun in the same position in the sky.

If we further move through the year, we will see the Sun track through different constellations over the course of the year. In late September through October, it would be in the constellation of Virgo, then move into Libra in November, followed by Scorpio, cross the tail of Ophiuchus, and then Sagittarius around Christmas and through the middle of January, then into Capricorn and Aquarius, then Pisces, Aries, Taurus, Gemini, Cancer, Leo, and then back to Virgo again one year later.

The line that the Sun follows in the sky through the course of the year is the **ecliptic**. It is defined by the Earth's orbit. The path of the ecliptic also defines a region in the sky known as the **zodiac**. Hence nearly all of the constellations that the Sun moves through are known as the zodiacal constellations.

1.5 The Seasons

The ecliptic is tilted by with respect to the Earth's equator and poles. This tilt is 23.5°. (When you look at a globe, you will now know why it is tilted and what this tilt is with respect to!) The tilt of the Earth with respect to its orbit, the ecliptic, also explains another phenomenon: the **seasons**.

On a date in late June, the Earth is oriented in such a way that the northern hemisphere is tilted toward the Sun. In fact, the line dividing day and night, the **terminator** cuts across the globe on the opposite side of the North Pole. People living above the Arctic Circle on this date would never see the Sun set. People living in the north not only get more sunlight during the day, but the light falling upon the surface is more direct, hence warming the northern hemisphere more. By contrast, the southern hemisphere gets much less light. As a result, the northern hemisphere experiences summer while the southern hemisphere experiences winter.

Three months later, the tilt of the Earth hasn't changed, but it has moved in its orbit so the alignment of the Earth with the Sun brings equal illumination over both northern and southern hemispheres.

Now if we wait another three months (hence, it is six months after we started), the Earth will be on the other side of the Sun. The southern hemisphere is getting not only longer but more direct solar illumination. Now summer will have started for the southern hemisphere, while the northern hemisphere moves into winter.

Three more months later and both hemispheres are now equally lit again. We are at the start of spring, with the north warming and the south cooling. If we move forward another three months, we are back to where we started and we are again at the start of the northern summer.

(a) Sun in Libra

(b) Sun in Scorpio

(c) Sun in Sagittarius

(d) Sun in Capricorn

(e) Sun in Aquarius

(f) Sun in Pisces

Figure 1.13: The Sun at Different Times of the Year
As the Earth moves in its orbit, the Sun will appear to be located in different constellations during different times of the year. These particular constellations are part of the zodiac.

1.6 The Phases of the Moon

One object we have seen tonight but have not explicitly discussed is the Moon.

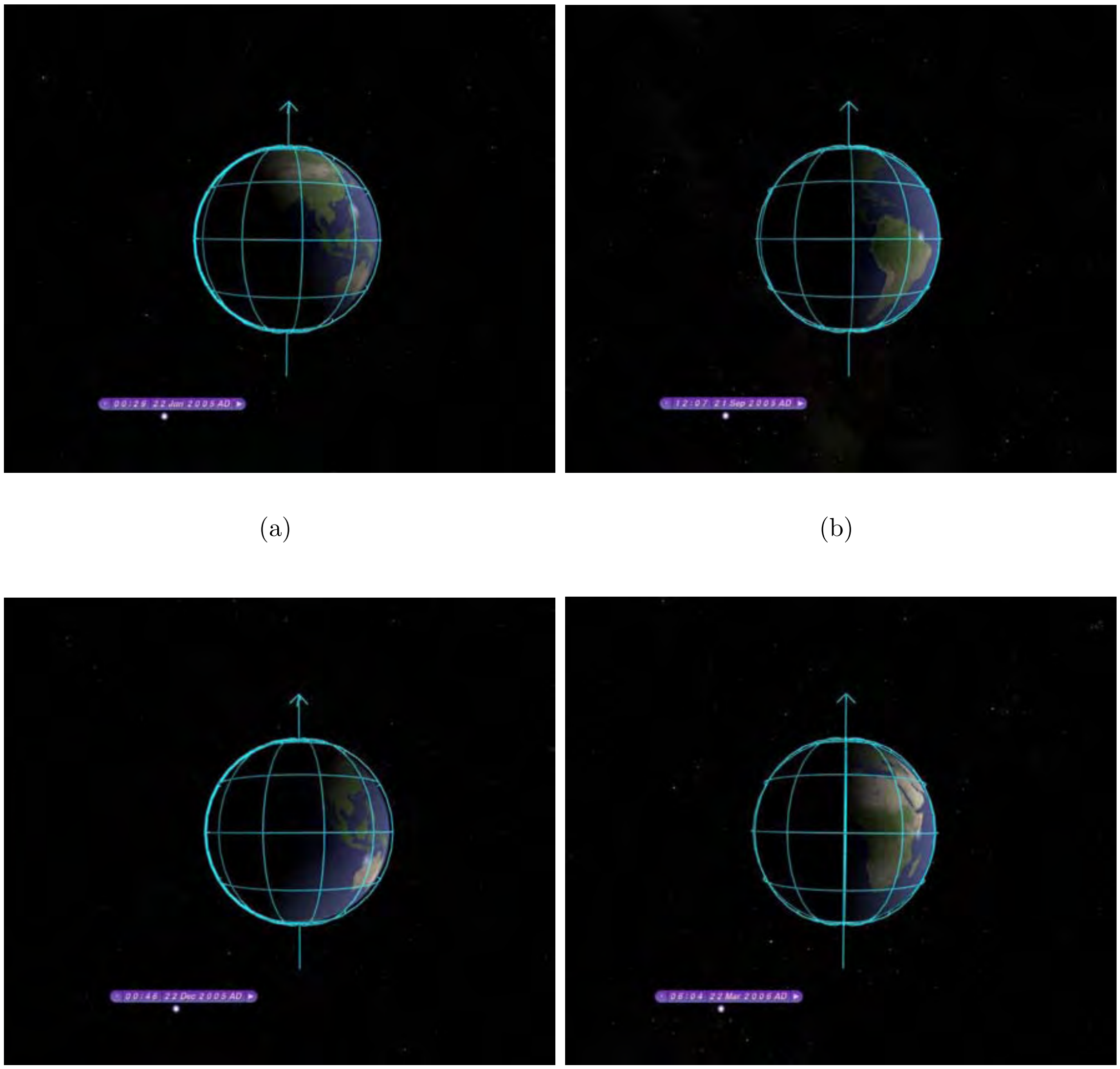
Let us lock to the Moon, so that the Earth is behind us. Tonight the we see a nearly **Full Moon**, but if we move forward a week, we will see the Moon wane to **3rd Quarter**. Notice the reason why it appears that only one side is lit is because of its orientation with the Sun.

Now we move forward another week and we see the Moon has less of its surface illuminated by the Sun. It is getting to the point of what is called **New Moon**.

Notice that for the New Moon, the Moon is between us and the Sun. And depending on the orientation of the Moon's orbit, the Moon can pass quite far from the Sun, when it is new, or in next month's case, pass quite close.

Finally if we lock back onto the Moon, and move another week forward in time, we find ourselves with a **1st Quarter** Moon. And yet another week later, the Moon continues to grow or *wax* until we are back at Full Moon. Here the Moon is opposite the Sun, on the other side of the Earth, and we see its fully illuminated face.

While the Moon orbits the Earth over the course of a month, its phases smoothly change. This is an effect entirely due to the relative orientation of the Moon with respect to the Sun. If we watch the Moon over its next orbit, we can tell what its phase will be depending on its orbital position: first starting with Full, then 3rd Quarter, then New, then 1st Quarter, and then back to Full again.

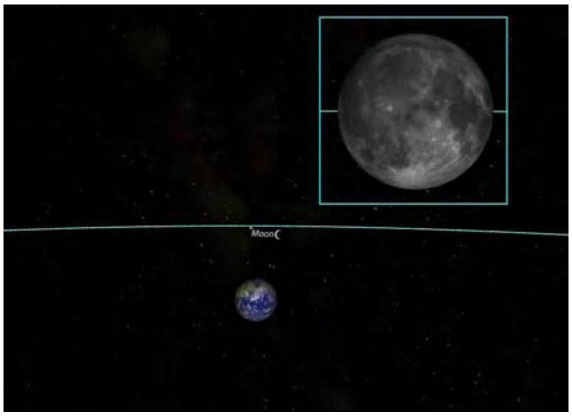


(a) (b)

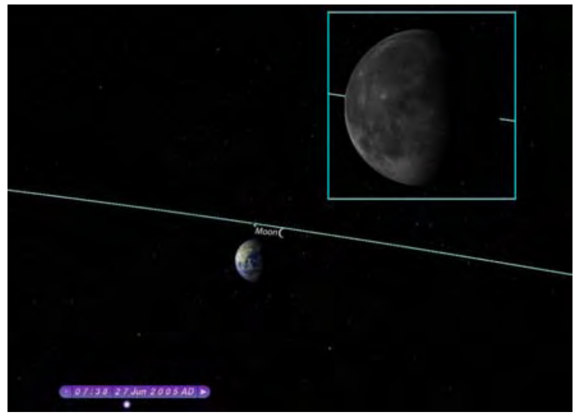
(c) (d)

Figure 1.14: The Seasons on Earth

Because the Earth is tilted with respect to its orbit, the amount of sunlight received by the northern and southern hemispheres vary throughout the year. In late June, the terminator *line dividing night and day leaves more of the northern hemisphere exposed to sunlight. During late September, both hemispheres receive equal amounts of Sun. Near the end of the year, the southern hemisphere gets the bulk of the light and heat. Finally in late March, the northern and southern hemispheres again reach parity.*

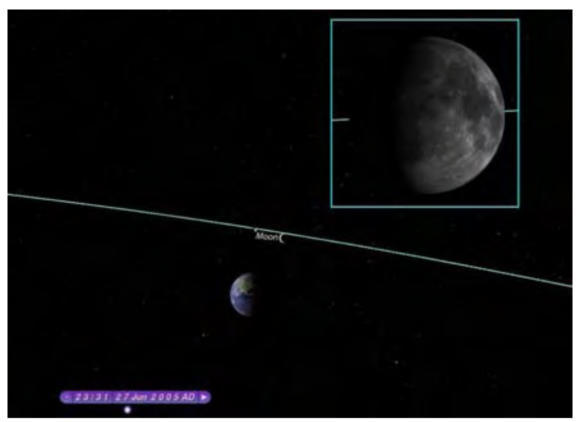


(a) Full Moon



(b) 3rd Quarter

(c) New Moon



(d) 1st Quarter

Figure 1.15: Phases of the Moon

Depending on the location of the Moon with respect to the Sun, the Moon's appearance will appear to shift through a series of phases*. A Full Moon is opposite the Sun from the Earth; a New Moon is in the same direction as the Sun. The 1st and 3rd quarter Moons are intermediate between the two.*