

The Celestial Sphere

If you take the opportunity to view the clear evening sky in some dark surroundings, away from the light and air pollution of civilization, you will find yourself face to face with the pieces of a puzzle that we call the universe. You will see an art form that has inspired the mind of man regardless of his race, creed, national origin or place in time. You will see a theatrical production of seemingly unlimited engagement. You may also be forced to seriously communicate with that entity that we have labeled as "self," for it is when we are faced with the vastness and timelessness of the universe that we come to see the insignificance and temporalness of the individual. You will also see the future. Man is on his way to the stars.

If you take the opportunity to view the clear evening sky in reasonably dark surroundings, you will no doubt notice many stars of varying brightness. You might assume that the brighter stars are relatively close to you and the fainter stars are more distant. A closer inspection will reveal that it is impossible to visually discern any differences in their distances, in fact all the stars appear to be at the same distance from you or any observer on the earth. All terrestrial observers appear to be in the center of a large celestial (heavenly) sphere that is cut off from further observation by the observer's apparent horizon. Thus we can see only one half of this apparent sphere at any one time.

Today we know that the stars are really at varying distances from the earth and that the night celestial sphere is only an apparent sphere that seems to have the stars fixed upon it. The concept of a celestial sphere, however, is still useful in understanding and demonstrating the motions of stars and other celestial objects as viewed by a terrestrial observer.

We can define the celestial sphere as an apparent sphere, surrounding a central earth, upon which the stars appear to be fixed. The celestial sphere is today a useful astronomical concept that does not exist in physical reality. It provides a certain amount of conceptual economy in dealing with appearances.

This concept of a celestial sphere is thought to have been introduced by the Greek philosopher Anaximander of Miletus in the sixth century B.C. He is also credited with the building of the first physical model of the celestial sphere. Observations of the stars have their origin further back in antiquity with the Chaldeans, Babylonians and Egyptians. These early civilizations observed the skies in order to develop agricultural and religious calendars. The observation and interpretation of the extra-terrestrial universe later became known as astronomy. The attachment to the observations of a belief in a form of celestial determinism tend to the development of astrology.

Although astronomical observations had been made much earlier, the Greek civilization seems to be the first civilization to be interested in demonstrations or explanatory models of the observations. Anaximander believed that the stars and planets moved under the earth in the same way that they seemed to move above the earth. This belief probably lead to his formation of the concept of a celestial sphere. The belief in the actual physical existence of a celestial sphere persisted for 2000 years.

The myriad stars seen in the evening sky present an endless possibility of convenient groupings. Somewhere in the history of man, the brighter stars came to be named and certain large groups of stars also came to be identified by a particular name. These groups of stars are called constellations. The grouping of stars into constellations is a purely arbitrary process. The origin of most of the constellations and their names has been lost in antiquity. Each constellation figure has been given a name that can usually be associated with some ancient myth, some animal, or common object, however some figures are without any recognizable pattern. Some names are old because the Greeks and western civilization adopted many of the earlier Babylonian constellation forms and names. Some constellations are comparatively recent because many new constellations were named during and after the discovery voyages to the southern hemisphere.

Astronomers have continued to use the old constellation names and by international agreement have set definite boundaries for each constellation. In ancient times constellation stars were confined within the outlines of the forms that they were supposed to represent. Many stars were not identified with a particular constellation. In 1930 the International

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The study of constellations is of no special importance in astronomy and belongs more in the study of mythology. We will be concerned with constellations because they can act as references to different parts of the celestial sphere.

Observations of the celestial sphere that are extended over a period of several hours will show that the celestial sphere appears to change its position with respect to the observer's horizon. The celestial sphere appears to move from east to west with respect to the horizon. This causes the stars and constellations to appear to rise in the east and set in the west. When looking south the apparent motion of the stars will be in the form of an arc produced by an apparent clockwise motion of the celestial sphere from east to west. When looking north, the apparent motion of the stars will be in the form of a complete circle or arc that is produced by an apparent counterclockwise motion of the celestial sphere from east to west.

The apparent east to west motion of the celestial sphere is referred to as its diurnal or daily motion. It was thought to be a true motion to the philosophers and astronomers of antiquity. A serious belief in a true motion of a celestial sphere extended from antiquity to the seventeenth century. The longevity of this concept will be easy to understand if you spend some uninterrupted hours observing the night sky. Your senses and intuition will tell you that you are stationary and that the sky is moving. The opposite is true. The apparent motion of the celestial sphere is a reflection of the earth's rotational motion.

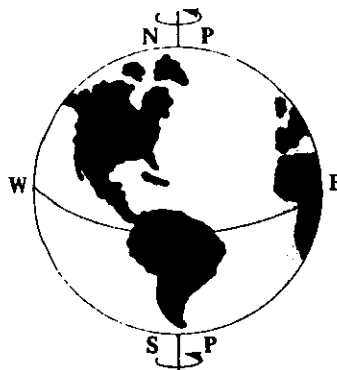


Figure 1. The earth rotates from west to east.

The earth rotates counterclockwise, west to east as seen from an observation point above the north pole and looking down at the earth. To a moving terrestrial observer, who easily imagines himself at rest, the celestial sphere will appear to be moving in the opposite direction from east to west. The west to east motion of the earth is reflected in the apparent east to west motion of the celestial sphere. You can easily demonstrate this to yourself by standing in the center of a

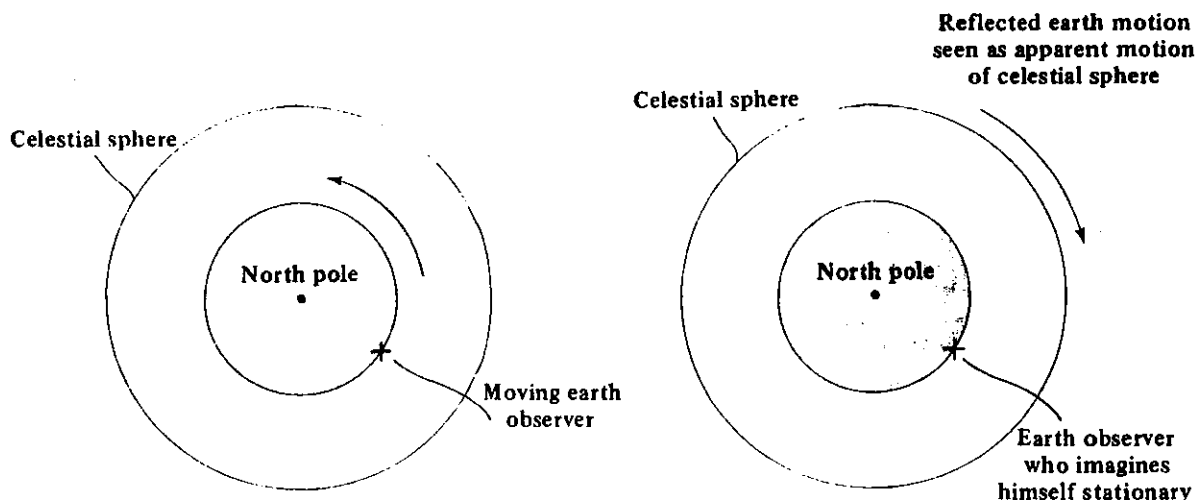


Figure 2. Reflected motion of the earth.

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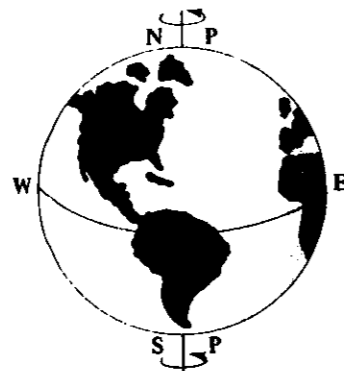


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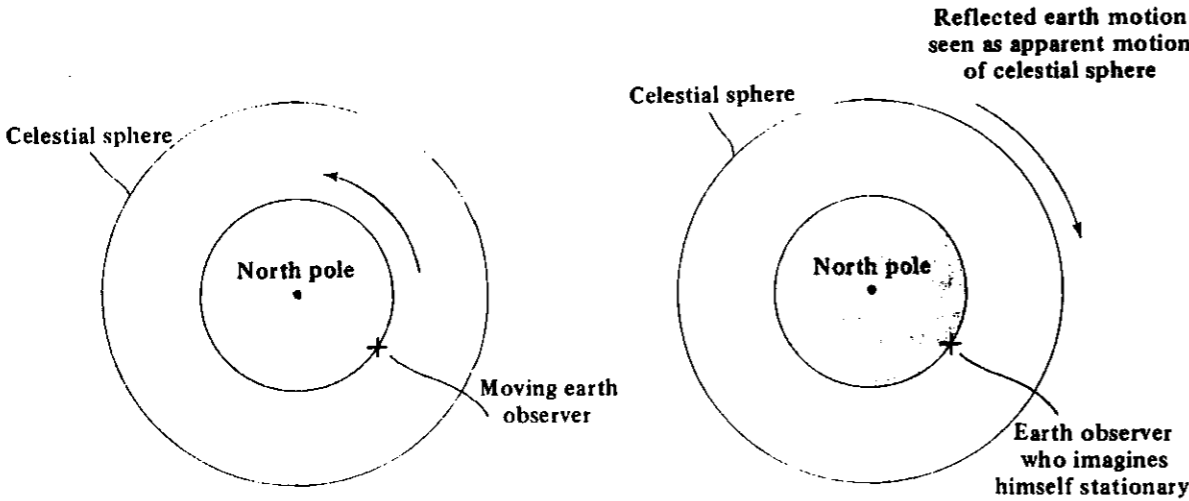


Figure 2. Reflected motion of the earth.

room and rotating counterclockwise from right to left. The objects on the wall will appear to move clockwise from ~~right~~ ^{left} to ~~left~~ ^{right}. The ceiling will appear to move counterclockwise. The apparent motion of the objects on the wall and the ceiling is the reflection of your motion.

The earth rotates counterclockwise 360° , with respect to the direction of a given star on the celestial sphere, in 23 hours, 56 minutes and 4 seconds ($23^h56^m04^s$). The celestial sphere will therefore appear to rotate 360° , by reflected motion, with respect to a fixed earth reference such as the observer's meridian, in 23 hours, 56 minutes and 4 seconds. The observer's meridian is part of a great circle which intersects the horizon at due north, passes through the observer's zenith and intersects the horizon again at due south. The 360° apparent rotational period of the celestial sphere is 3 minutes and 56 seconds shorter than the 24 hour solar or civil day. The celestial sphere will therefore appear to rotate slightly more than 360° in one solar day. The apparent 360° rotation of the celestial sphere in 23 hours, 56 minutes and 4 seconds is the period of the diurnal (daily) motion of the celestial sphere.

The apparent 360° rotation of the celestial sphere in 23 hours, 56 minutes and 4 seconds is referred to as a sidereal day. The sidereal day is the time required for two successive meridian crossings of the same star. The 3 minute and 56 second difference between the sidereal day and the mean solar day causes the phenomena of the seasonal constellations.

In the beginning of February each year, the rectangle and three belt stars of the majestic constellation of Orion can be seen in the South. By the end of April, the Zodiac constellation of Leo will have replaced Orion in the night sky. Leo will be replaced by Scorpio in July and the Great Square of Pegasus will be the most prominent southern constellation in November. Orion will again return to dominate the southern night skies during the following February.



Courtesy of Griffith Observer.

Table 1 shows the apparent angular movement of the celestial sphere for different periods of mean solar time. Since the mean solar day is 3^m56^s longer than the sidereal day, the celestial sphere will appear to move a little more than 360° in a 24^h mean solar day period. According to Table 1, the celestial sphere will appear to move approximately 361° in a 24^h mean solar day. This means that if the sky is observed at a constant time each night (for instance, 8:00 P.M.), the stars will be approximately 1° further to the west each successive night. After a period of 30 days the stars and constellations will appear to have "drifted westward" by 30 degrees. A constellation that is rising in the east, at 8:00 P.M., in the fall, will, a half year later ($180 \text{ days} = 180^\circ$), be setting in the west at 8:00 P.M. Figure 3 demonstrates the phenomena of the seasonal constellation.

TABLE 1
Angular Movement for Mean Solar Time Intervals

Angular Movement	Mean Solar Time Interval
$(360^\circ/24^h00^m15^s)$ 1°	1^h $4^m (60^m/15^s)$

The earth's axis of rotation passes through the terrestrial north and south poles. When the terrestrial axis is extended to intersect the celestial sphere, it does so at points that have been labeled P_n and P_s . P_n , pronounced "P sub-n", is the position of the apparent rotational axis of the celestial sphere in the celestial northern hemisphere. P_s , pronounced "P sub-s", is the position of the apparent rotational axis of the celestial sphere in the celestial southern hemisphere.

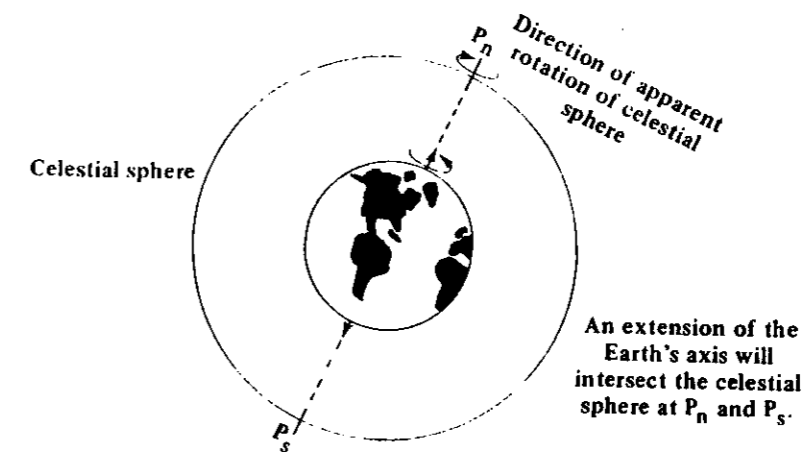


Figure 4. Terrestrial and celestial poles.

The position of P_n on the celestial sphere is approximately $3\frac{1}{4}^\circ$ away from the star Polaris, the Pole Star. Since the celestial sphere appears to rotate, counterclockwise, around the P_n point, it will also appear to rotate around the nearby star Polaris. The rotational movement of Polaris, in a circle of radius $3\frac{1}{4}^\circ$, will make it appear to stay in the same position above the true north direction of the observer's horizon. Since Polaris is always found in the true north direction it has come to be known as the "North Star."

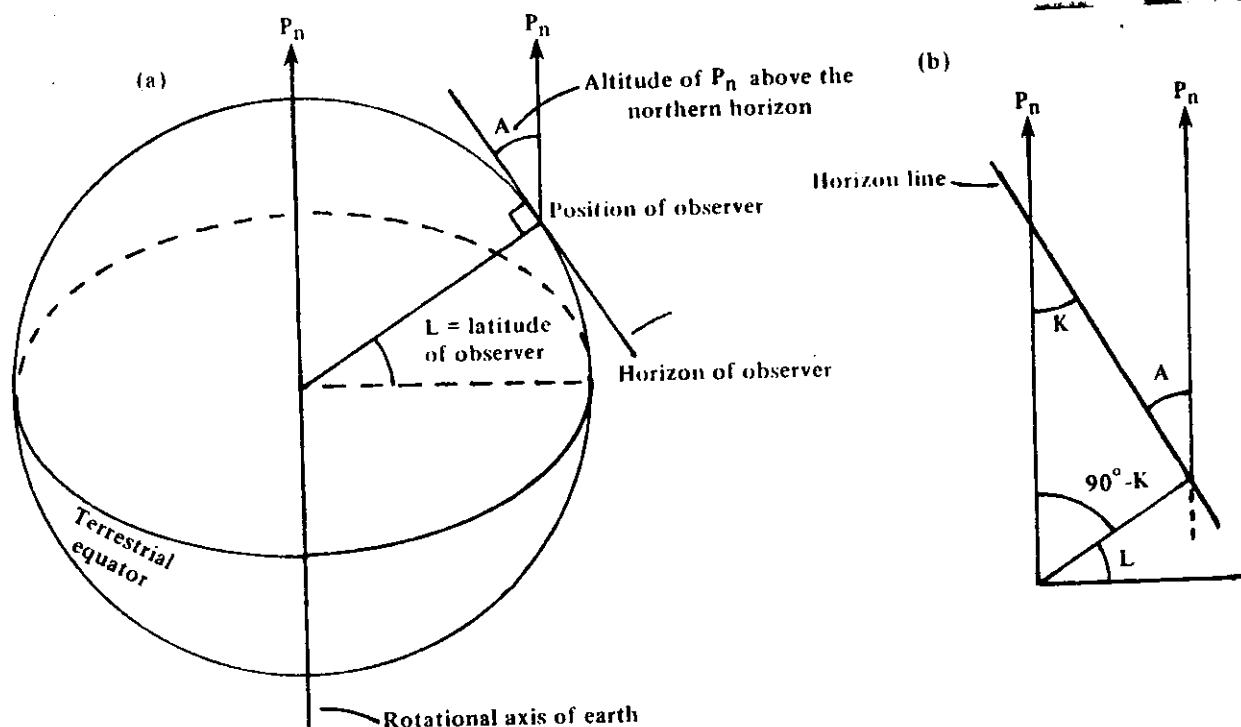
The altitude of the apparent rotational axis, P_n , above the true north direction of the observer's horizon is determined by the observer's geocentric latitude. The relationship between the altitude of the P_n point and the observer's geocentric latitude can be derived from geometric considerations.

Consider an observer at some position in the northern hemisphere of the terrestrial globe as shown in Figure 5 (a). The observer's geocentric latitude, which is the angle at the center of the earth between the observer's position and the plane of the terrestrial equator, is labeled as angle L (latitude). The observer's apparent horizon is a plane that is tangent to the earth and perpendicular to a line extended to the center of the earth. The altitude of P_n above the northern horizon, as seen by the observer, is labeled as angle A (altitude). The rotational axis of the earth in Figure 5 (a) points to P_n .

Figure 5 (b) shows the important angles in Figure 5 (a). An important relationship can be derived:

- | | |
|---|---|
| $\angle A = \angle k$ | 1. Angle A is equal to angle k because the two basically parallel lines to P_n are cut by a transversal (the horizon line) making equal alternate interior angles. |
| $90^\circ - \angle k = 90^\circ - \angle A$ | 2. A triangle has 180 interior degrees. The angle between the horizon line and the line from the observer to the center of the earth consists of 90 of the total number of degrees. Ninety degrees must be divided between the other two angles. Since one angle is k degrees the other angle will be equal to $90^\circ - \angle k$. Because $\angle k$ is equal to $\angle A$, the angle between the rotational axis and the observer is equal to $90^\circ - \angle A$. |
| $90^\circ = (90^\circ - \angle A) + \angle L$ | 3. The angle between the rotational axis and the equatorial plane is equal to 90° . This 90° angle is equal to the sum of the other two angles ($90^\circ - \angle k$) and $\angle L$. Since $\angle k$ equals $\angle A$, a substitution can be made as stated. |
| $\angle A = \angle L$ | 4. If $(\angle A - 90^\circ)$ is added to both sides of the equation, the equation reduces to a simple equality between $\angle A$ and $\angle L$. |

The above equation states that for any terrestrial observer, the altitude of P_n (or Polaris as an approximation) above the observer's northern horizon is equal to the geocentric latitude of the observer.

Figure 5. The altitude of P_n .

The stars and constellations that can be seen, when the celestial sphere is observed in the direction of the north point on the horizon, can be divided into two groups for terrestrial observers at mid-latitudes. Circumpolar stars and constellations are those seen, for a particular terrestrial observer, whenever the skies are clear. They are seen at anytime of night, on any night of the year. They could even be seen in the daytime if the light of the sun did not make them indistinguishable from the bright sky. Circumpolar stars and constellations are located between the apparent celestial pole and a circle with an angular radius equal to the altitude of the apparent celestial pole. In mid-northern latitudes, the Big Dipper (Ursa Major—Big Bear) is probably the best known and most easily recognized of the circumpolar constellations. The other circumpolar constellations, for mid-latitudes, include the equally famous Little Dipper (Ursa Minor—Little Bear), Cassiopeia The Queen, Cepheus the King and Draco the Dragon.

Noncircumpolar stars and constellations are those that are blocked from view by the observer's horizon. These are stars and constellations that appear to rise in the east and set in the west because of the reflected motion of the earth's rotation.

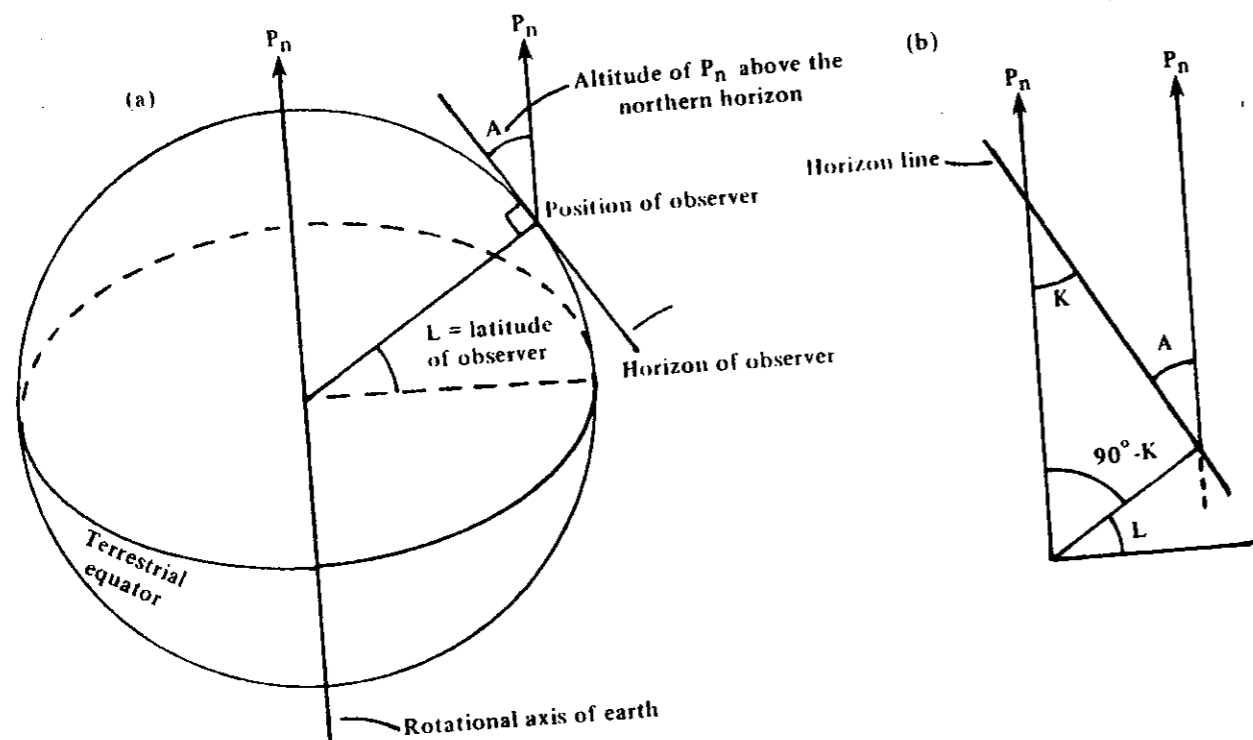
In order to determine whether a particular star or constellation is circumpolar for a given terrestrial observer, it is necessary to determine the position of the celestial axis point in relation to the terrestrial observer.

Figure 6 (a) is a star map of the north circumpolar region of the celestial sphere. The concentric circles represent celestial areas, centered on P_n , increasing in radius by 10° up to a maximum of 50° . If a star is nearer to the north celestial pole, P_n , than the pole is to the horizon, at a given latitude, the star will not cross the horizon as the celestial sphere appears to rotate and therefore it will be a circumpolar star at that latitude. The altitude of P_n above the northern horizon is determined by the latitude of the observer, therefore whether a star or constellation is circumpolar or not is determined by the latitude of the observer.

For example, if the latitude of an observer is 40°N , then P_n will be 40° above the observer's northern horizon. Any star that is closer than 40° to the P_n point will be circumpolar because it will not disappear below the observer's horizon as the celestial sphere appears to rotate.

The relative number of circumpolar stars that an observer can see is a function of latitude. The relative area of the celestial sphere that an observer can see, and the rising and setting angles of the stars are also a function of latitude.

The celestial equator is a great circle on the celestial sphere that is at all places 90° away from the P_n and P_s celestial pole positions. The celestial equator is actually a projection of the terrestrial equator on to the apparent celestial sphere. It divides the celestial sphere into two hemispheres in exactly the same way that the terrestrial equator divides the earth.

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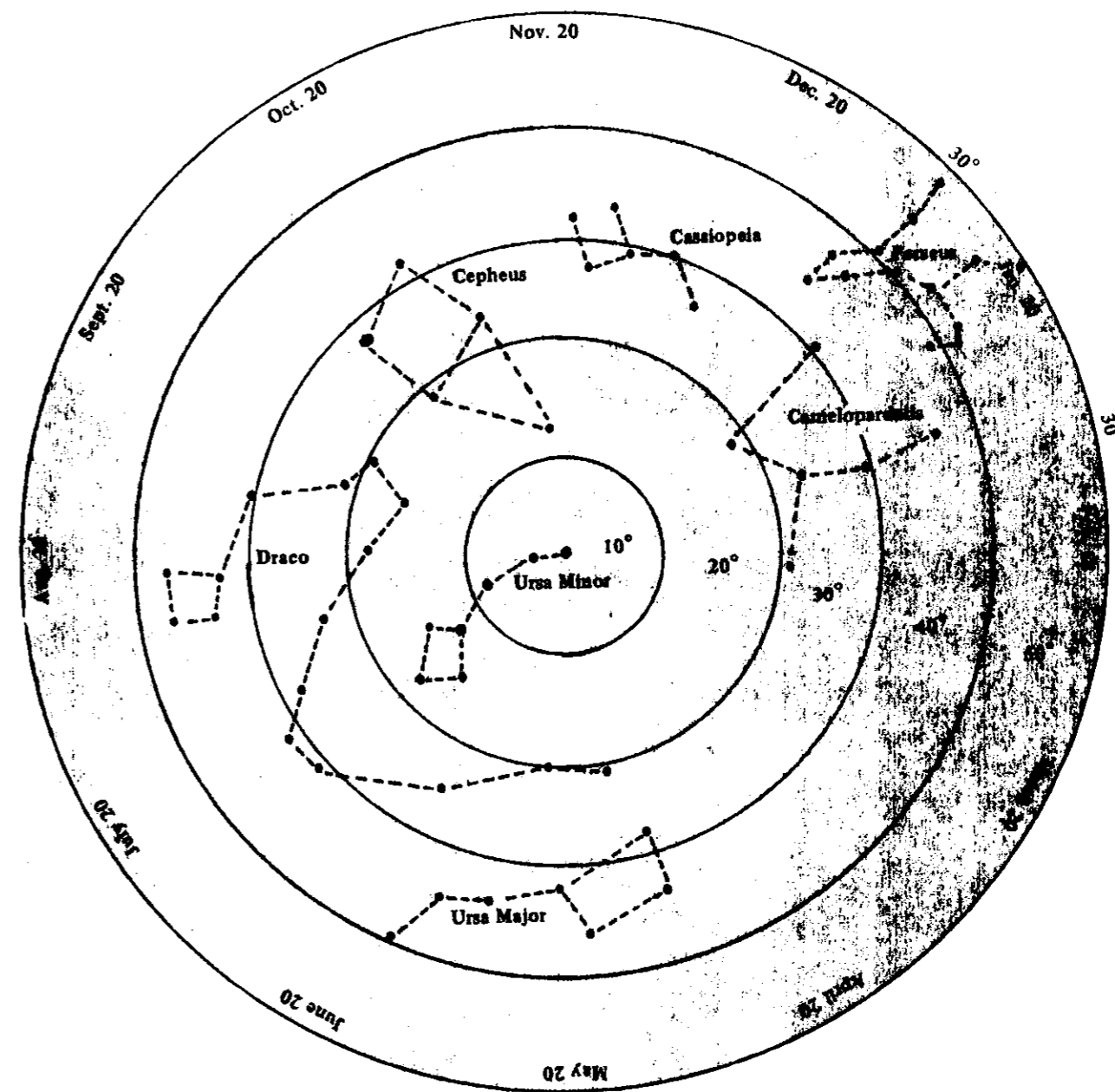


Figure 6 (a). North circumpolar region star map.

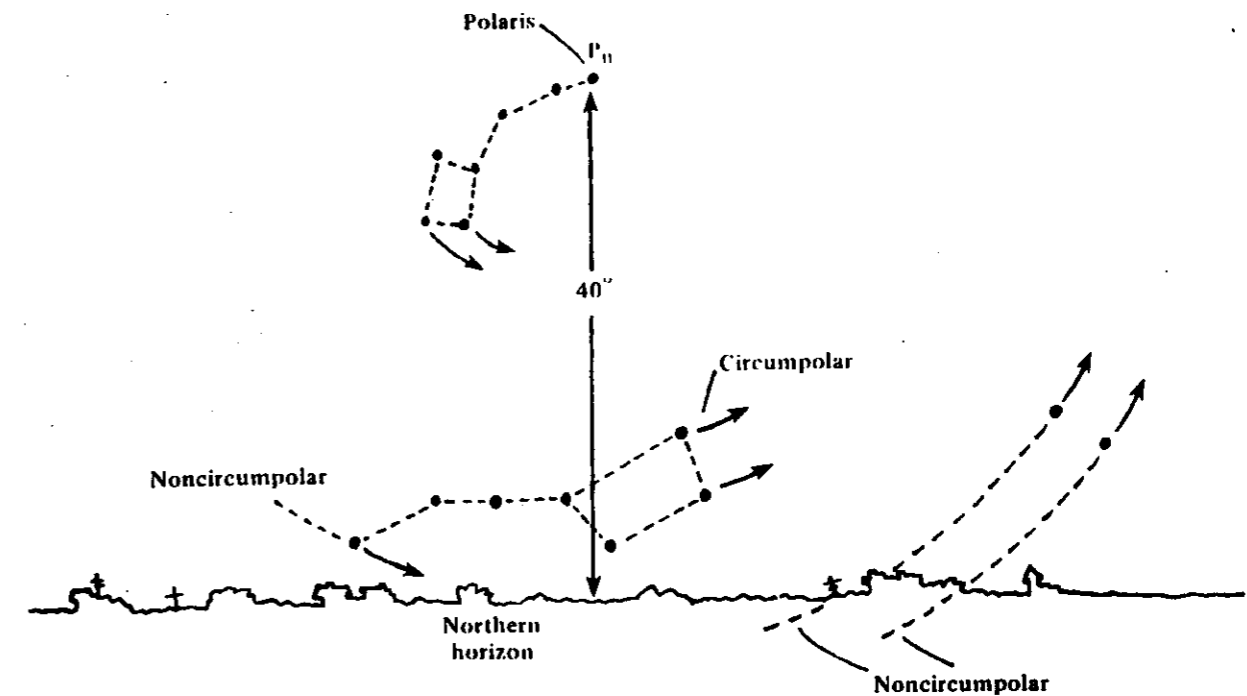


Figure 7. Circumpolar stars for 40° north latitude.

into a northern and southern hemisphere. A knowledge of the altitude of the celestial equator at the observer's meridian allows a determination of the relative area of the celestial sphere that the observer can see and a determination of the rising and setting angles of the stars.

Consider an observer on the equator (latitude 0°). Figure 8 (a) illustrate the positions of P_n , P_s and the celestial equator as they are found on the observer's meridian. Figure 8 (b) illustrates the movement of the celestial sphere as seen from the equator.

An observer at 0° latitude will have the P_n point on the northern horizon, at the due north point, since the altitude of P_n is equal to the 0° latitude of the equator.

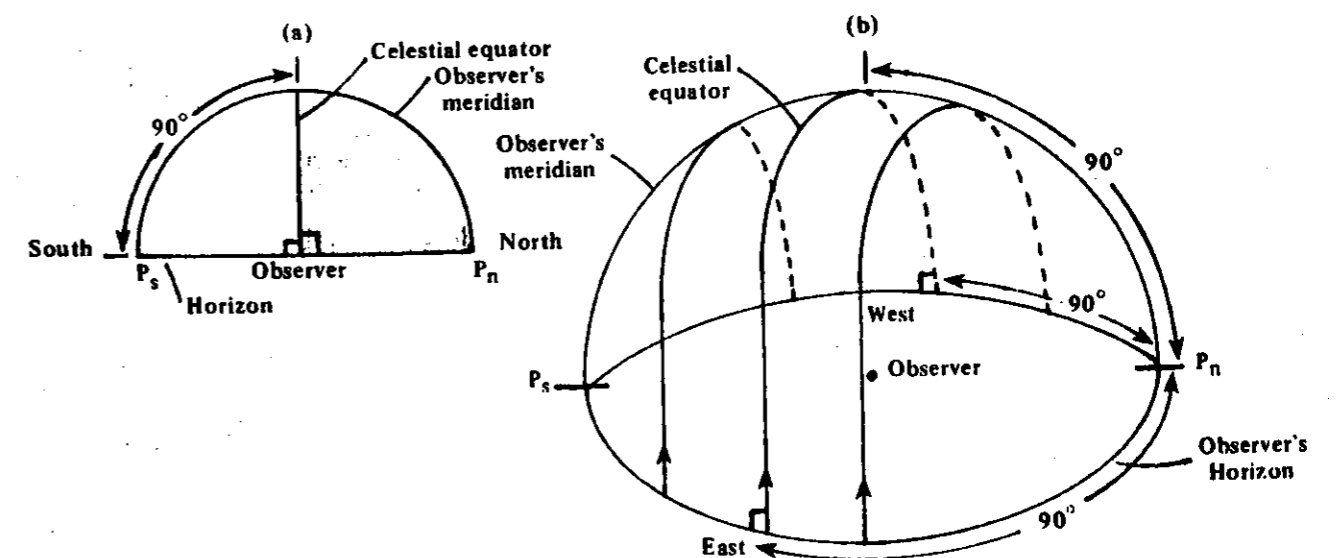
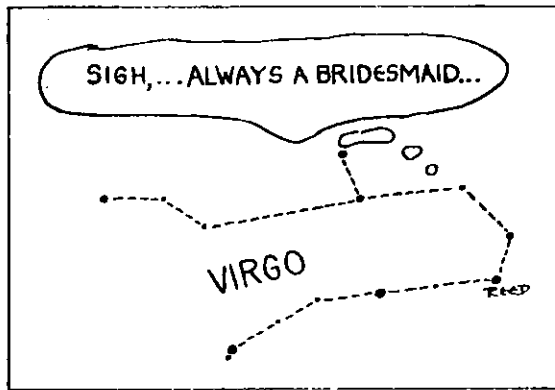


Figure 8. The stars at latitude 0°.



Courtesy of Griffith Observer.

The word constellation is derived from the Latin "with stars". A few of the commonly known constellations such as the Big Dipper and the Little Dipper are asterisms. An asterism is a part of a larger constellation that contains a well known and recognizably shaped group of stars. The Big Dipper, for instance, is a part of Ursa Major.

The due east and due west points are 90° away from all meridian points. The celestial equator will cross the apparent horizon at the due east and due west points for all observers regardless of latitude. This is because the P_n and P_s points will always be 180° apart on any observer's meridian and the celestial equator must always be half way between the two apparent pole points.

The celestial equator will reach from due east to due west and cross the observer's meridian at the zenith, 90° above the P_n point which is on the northern horizon. The stars at the equator will appear to rise perpendicular to the eastern horizon and set perpendicular to the western horizon as the celestial sphere appears to rotate from east to west. The entire celestial sphere will be above the horizon of the observer at some time during the day. All stars will therefore be noncircumpolar stars since all stars will cross the horizon at some time. Since the celestial sphere can be seen from the P_n point to the P_s point, the entire celestial sphere will be visible at ~~some~~ time during the year to an observer at the equator.

An observer at $23\frac{1}{2}^\circ$ north latitude would have the P_n point on the meridian at an altitude of $23\frac{1}{2}^\circ$ above the northern horizon. The celestial equator will extend from due east to due west and cross the observer's meridian at a position 90° away from the P_n position or $66\frac{1}{2}^\circ$ above the southern horizon as shown in Figure 9 (a).

$$180^\circ - (23\frac{1}{2}^\circ + 90^\circ) = 66\frac{1}{2}^\circ$$

The stars at latitude $23\frac{1}{2}^\circ$ north will appear to rise in the east at an angle of $66\frac{1}{2}^\circ$ to the south and set in the west at an angle of $66\frac{1}{2}^\circ$ to the south since the stars will always appear to move along arcs that are parallel to the celestial equator. Figure 9 (b) illustrates the apparent motion at latitude $23\frac{1}{2}^\circ$ N.

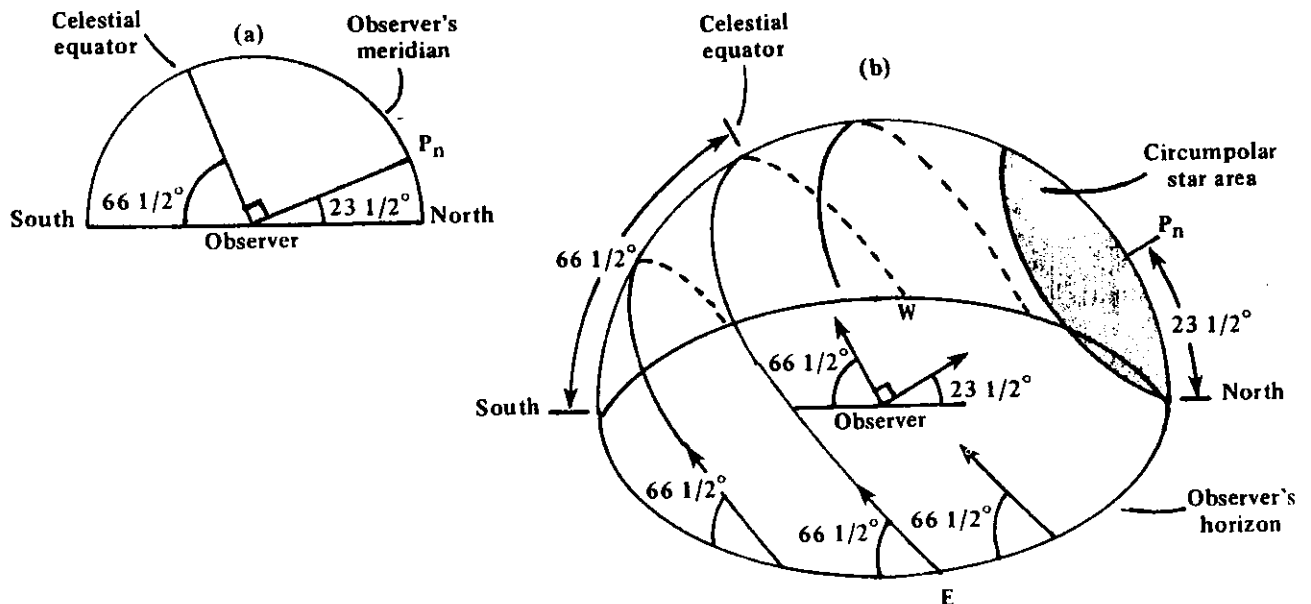
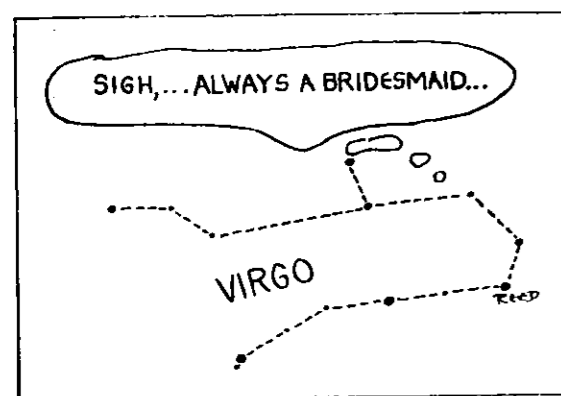


Figure 9. The stars at latitude $23\frac{1}{2}^\circ$ north.



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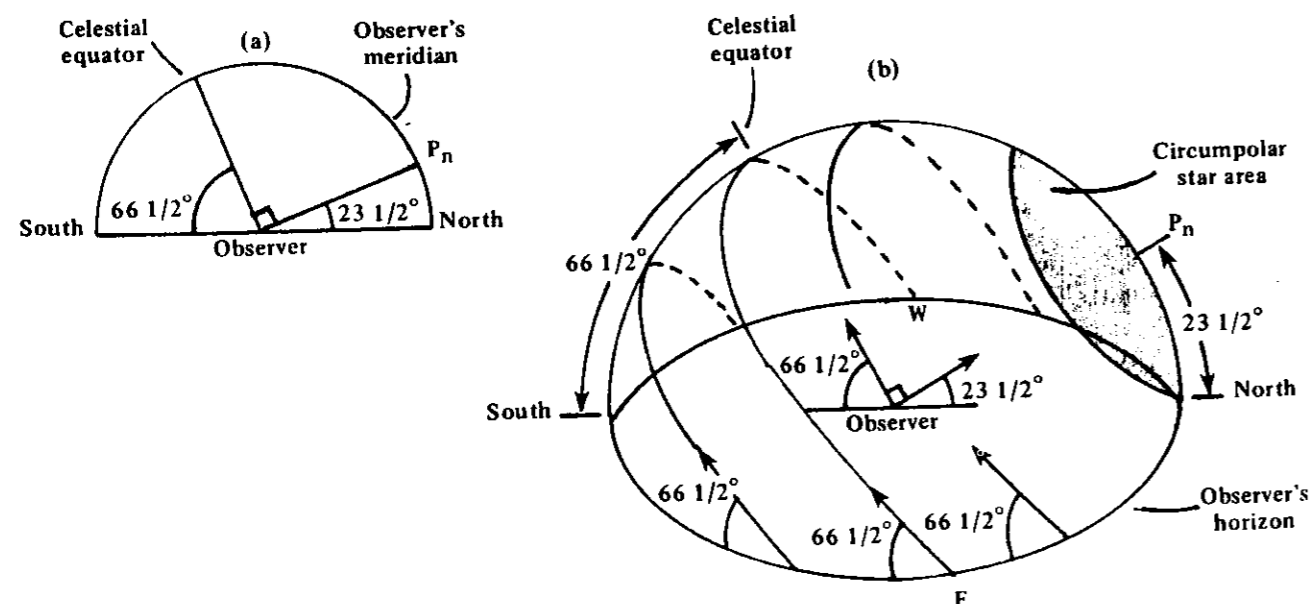


Figure 9. The stars at latitude $23\frac{1}{2}^\circ$ north.

The P_s point will be $23\frac{1}{2}^\circ$ below the observer's southern horizon since it is 180° away from the P_n position. Stars and constellations within a circle of radius $23\frac{1}{2}^\circ$ from P_s will be unobservable to the observer at $23\frac{1}{2}^\circ$ north latitude. Fewer stars will therefore be visible to an observer at latitude $23\frac{1}{2}^\circ$ north as compared to an observer at latitude 0° .

Those stars and constellations that lie within $23\frac{1}{2}^\circ$ of the P_n position will never disappear below the northern horizon and will be circumpolar. Only Ursa Minor, The Little Bear or Little Dipper, will be a circumpolar constellation at $23\frac{1}{2}^\circ$ north. Obviously, there will be more circumpolar stars and constellations at latitude $23\frac{1}{2}^\circ$ N as compared to latitude 0° .

An observer at 40° north latitude will have the P_n point on the meridian at an altitude of 40° above the northern horizon. The celestial equator will extend from due east to due west and cross the observer's meridian at a position 90° away from the P_n position or 50° above the southern horizon as shown in Figure 10 (a).

$$180^\circ - [40^\circ + 90^\circ] = 50^\circ$$

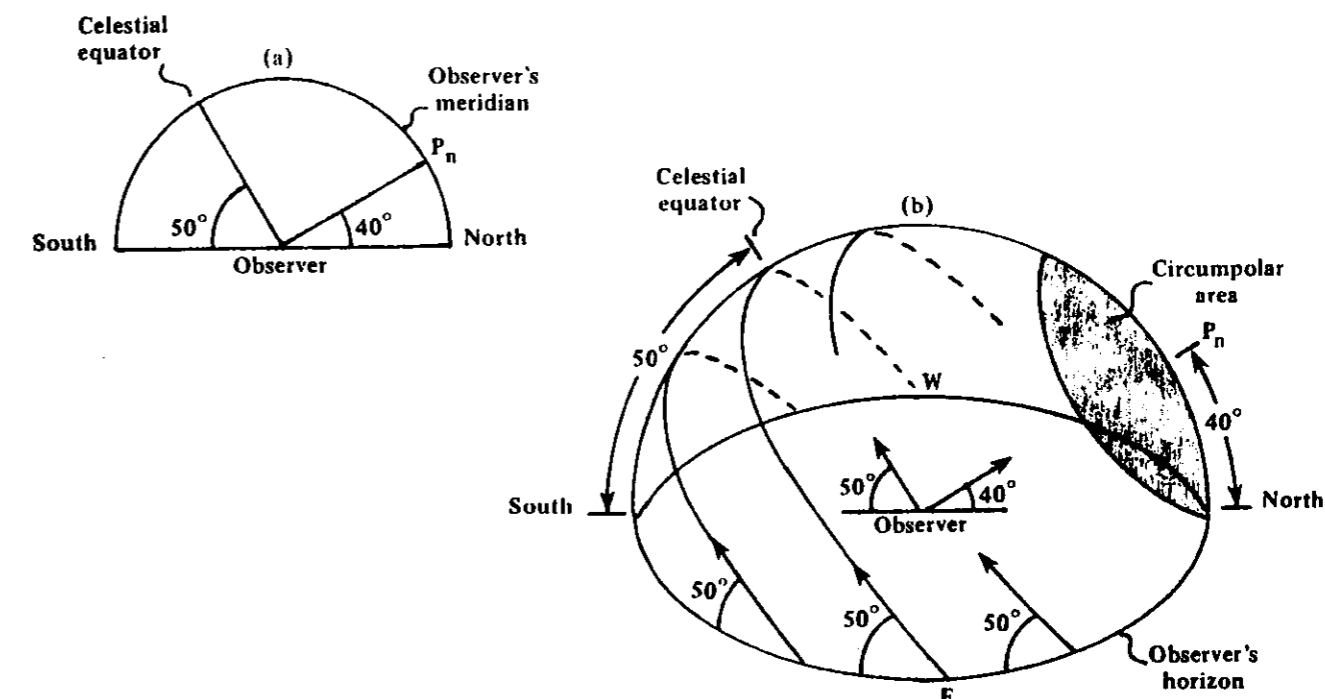


Figure 10. The stars at latitude 40° north.

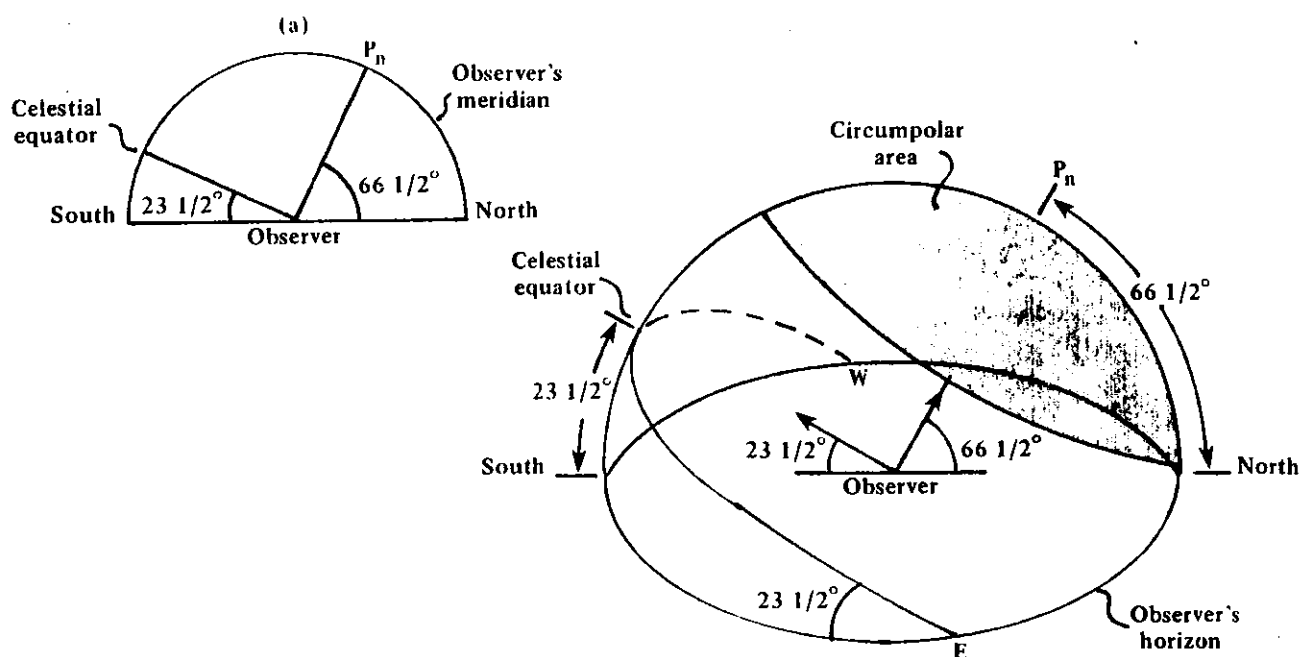
The stars at latitude 40° north will appear to rise in the east at an angle of 50° to the south. The stars will appear to move along arcs that are parallel to the plane of the celestial equator at latitude 40° north. Figure 10 (b) illustrates the apparent motion of the stars at latitude 40° north.

The P_s point will now be 40° below the observer's southern horizon. The stars and constellations that are found within a circle of radius 40° from P_s will not be visible to the observer at 40° north latitude. Since more stars and constellations will lie within a circle of radius 40° from P_s as compared to a circle of radius $23\frac{1}{2}^\circ$ from P_s , more stars will be unobservable to an observer at latitude 40° north than at latitude $23\frac{1}{2}^\circ$ north.

Those stars and constellations that lie within 40° of the P_n position will never disappear below the northern horizon and will therefore be circumpolar at this latitude. Since more stars and constellations will be visible within a circle of radius 40° as compared to a circle of radius $23\frac{1}{2}^\circ$, there will be more circumpolar stars and constellations at latitude 40° north than at latitude $23\frac{1}{2}^\circ$ north. Ursa Minor, Ursa Major, Cepheus, Cassiopeia, Draco the Dragon and the large but faint and less well known constellation Camelopardalis, the Camel, will all be circumpolar at latitude 40° north.

An observer at $66\frac{1}{2}^\circ$ north latitude will have the P_n point on the meridian at an altitude of $66\frac{1}{2}^\circ$ above the northern horizon. The celestial equator will extend from due east to due west and cross the observer's meridian at a position 90° away from the P_n position or $23\frac{1}{2}^\circ$ above the southern horizon as shown in Figure 11 (a).

$$180^\circ - [66\frac{1}{2}^\circ + 90^\circ] = 23\frac{1}{2}^\circ$$

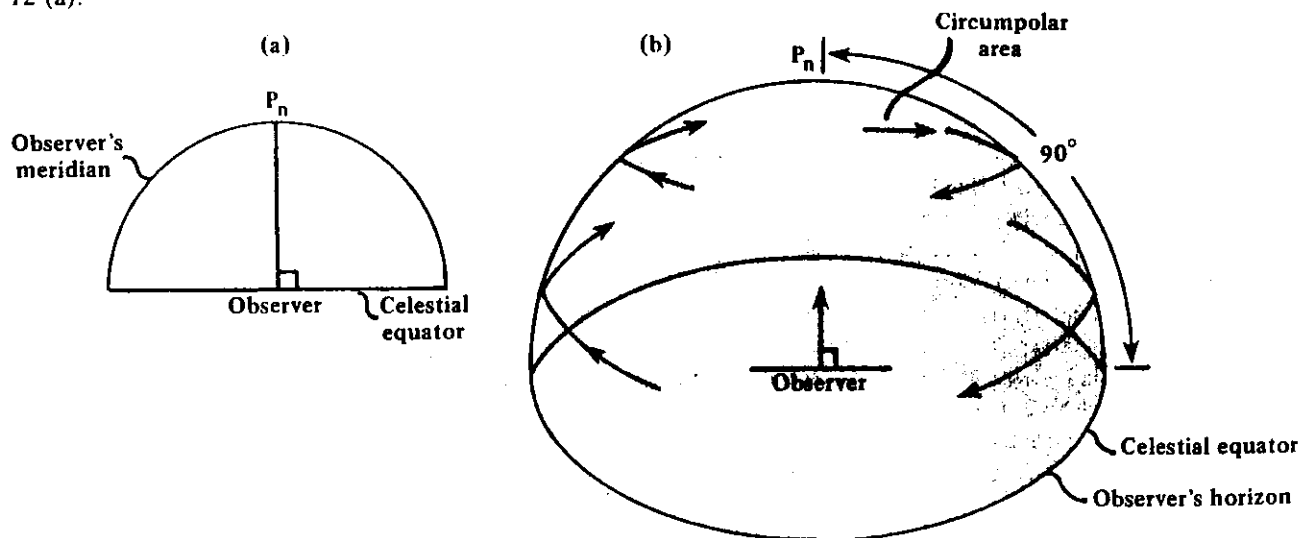
Figure 11. The stars at latitude $66\frac{1}{2}^\circ$ north.

The stars at latitude $66\frac{1}{2}^\circ$ north will appear to rise in the east at an angle of $23\frac{1}{2}^\circ$ to the south and set in the west at an angle of $23\frac{1}{2}^\circ$ to the south. The stars will again appear to move along arcs that are parallel to the plane of the celestial equator. Figure 11 (b) illustrates the apparent motion of the stars at latitude $66\frac{1}{2}^\circ$ north.

The P_s point, at this latitude, will be $66\frac{1}{2}^\circ$ below the observer's southern horizon. The stars and constellations that are within a circle of radius $66\frac{1}{2}^\circ$ from P_s will not be visible to the observer at latitude $66\frac{1}{2}^\circ$ north. Since more stars and constellations will lie within a circle of radius $66\frac{1}{2}^\circ$ from P_s as compared to a circle of radius 40° from P_s , more stars will be unobservable to an observer at latitude $66\frac{1}{2}^\circ$ north than at latitude 40° north.

Those stars and constellations that lie within $66\frac{1}{2}^\circ$ of the P_n position will never disappear below the northern horizon and will be circumpolar. Since more stars and constellations will be contained within a circle of radius $66\frac{1}{2}^\circ$ as compared to a circle of radius 40° , there will be more circumpolar stars and constellations at latitude $66\frac{1}{2}^\circ$ north than at latitude 40° north. Some of the prominent seasonal constellations for lower latitudes, such as Hercules, Lyra and Cygnus, will appear all year long to an observer at latitude $66\frac{1}{2}^\circ$ north.

An observer at 90° north latitude, the terrestrial North Pole, will have the P_n point at the zenith position, 90° above all directions on the horizon. The celestial equator will conversely be on the horizon in all directions as shown in Figure 12 (a).

Figure 12. The stars at latitude 90° north.

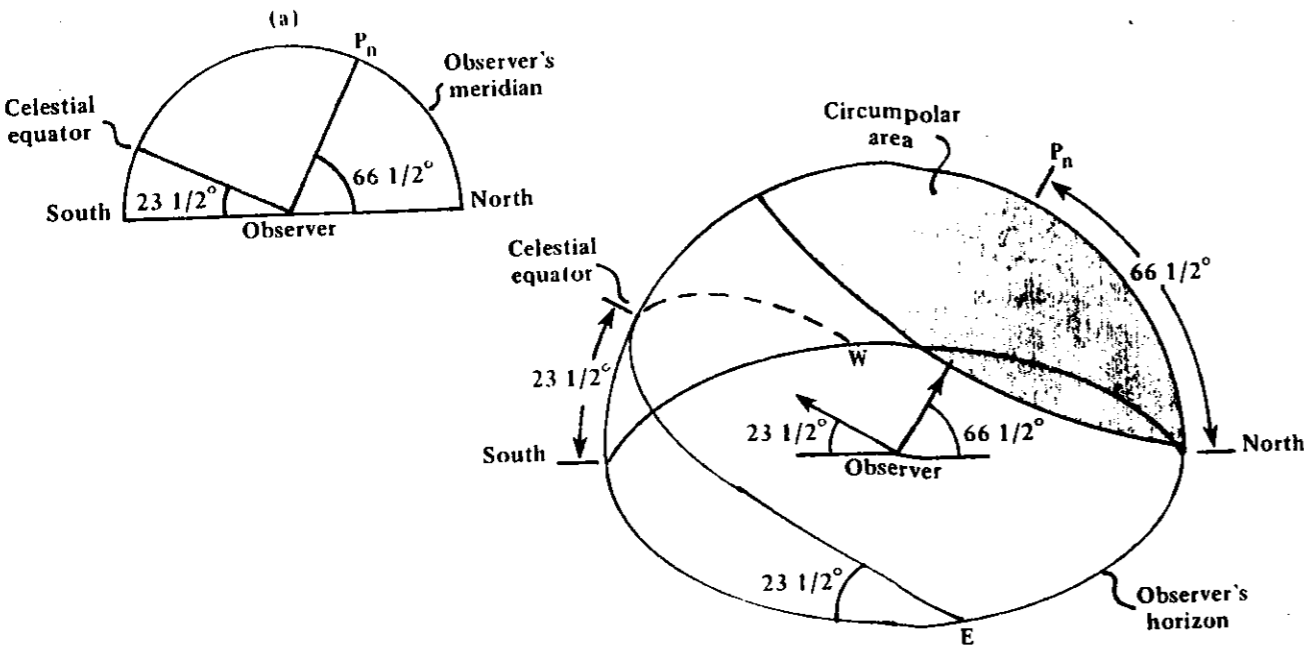


Figure 11. The stars at latitude 66 1/2° north.

The stars at latitude 66 1/2° north will appear to rise in the east at an angle of 23 1/2° to the south and set in the west at an angle of 23 1/2° to the south. The stars will again appear to move along arcs that are parallel to the plane of the celestial equator. Figure 11 (b) illustrates the apparent motion of the stars at latitude 66 1/2° north.

The P_s point, at this latitude, will be 66 1/2° below the observer's southern horizon. The stars and constellations that are within a circle of radius 66 1/2° from P_s will not be visible to the observer at latitude 66 1/2° north. Since more stars and constellations will lie within a circle of radius 66 1/2° from P_s as compared to a circle of radius 40° from P_s , more stars will be unobservable to an observer at latitude 66 1/2° north than at latitude 40° north.

Those stars and constellations that lie within 66 1/2° of the P_n position will never disappear below the northern horizon and will be circumpolar. Since more stars and constellations will be contained within a circle of radius 66 1/2° as compared to a circle of radius 40°, there will be more circumpolar stars and constellations at latitude 66 1/2° north than at latitude 40° north. Some of the prominent seasonal constellations for lower latitudes, such as Hercules, Lyra and Cygnus, will appear all year long to an observer at latitude 66 1/2° north.

An observer at 90° north latitude, the terrestrial North Pole, will have the P_n point at the zenith position, 90° above all directions on the horizon. The celestial equator will conversely be on the horizon in all directions as shown in Figure 12 (a).

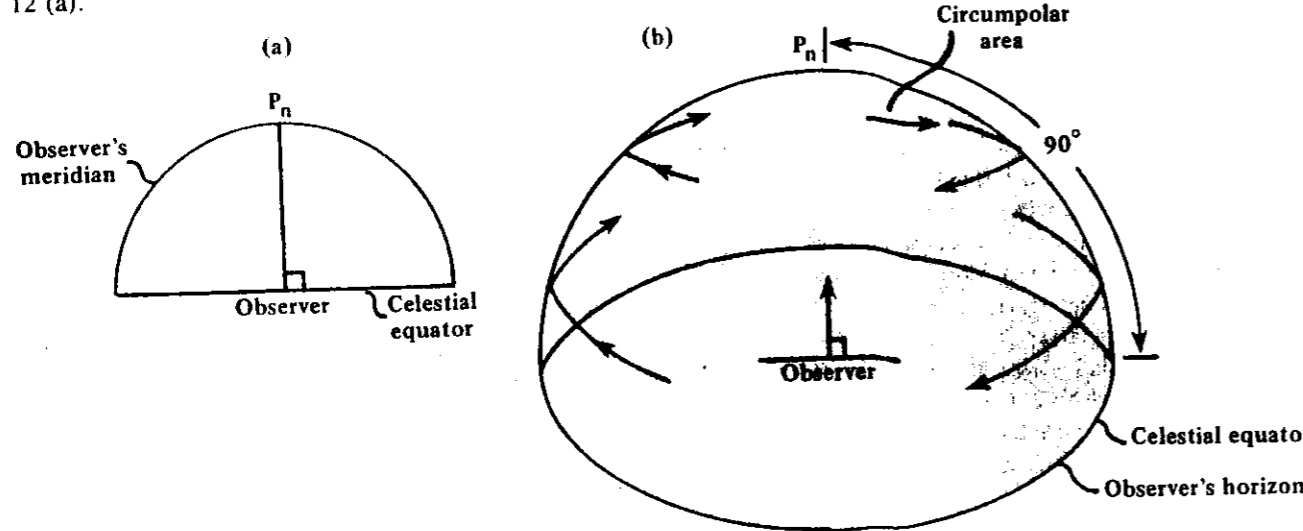
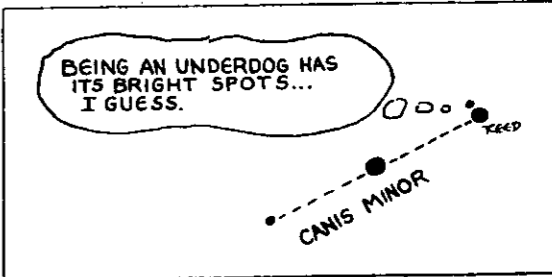


Figure 12. The stars at latitude 90° north.

The stars at the North Pole will neither rise nor set. They will constantly move counterclockwise in circles that always remain the same altitude above the horizon. All the visible stars and constellations would be circumpolar to the observer. Since more stars lie within a circle of radius 90° from P_n (entire northern hemisphere of the celestial sphere) as compared to a circle of radius 66 1/2°, there will be more circumpolar stars and constellations at latitude 90° north than at latitude 66 1/2° north. All stars that are found in the southern hemisphere of the celestial sphere will be unobservable at the north pole. Since more stars and constellations will lie within a circle of radius 90° from P_s as compared to a circle of radius 66 1/2° from P_s , more stars will be unobservable to an observer at latitude 90° north than at latitude 66 1/2° north.

Greek travelers knew that as you moved farther north the constellations of the Big and Little Bear would rise higher in the sky. The Greek word for bear was "Arkto". Northern regions where the Big and Little Bear were visible were called "Arktikos". Today we define the "Arctic" regions as the land which lies above the "Arctic" circle.



Courtesy of Griffith Observer.

It can be seen that several geocentric observations are a function of the latitude of the observer. It has been shown that as a terrestrial observer moves from the equator (latitude 0°) to the North Pole (latitude 90°N):

1. The altitude of P_n above the northern horizon point will increase numerically from 0° at the equator to 90° at the North Pole.
2. The altitude of the intersection of the celestial equator and the observer's meridian will decrease numerically from 90° at the equator to 0° at the North Pole.
3. The rising and setting angles of the stars with respect to the observer's apparent horizon will decrease numerically from 90° at the equator to 0° at the North Pole. The stars at each latitude will appear to move from east to west through an arc that is parallel to the plane of the celestial equator at that latitude.
4. The position of the P_s point will move from the place where the meridian intersects the southern horizon (equator) to a position at the nadir, which is the place on the meridian that is directly below the observer (North Pole). This will cause the number of stars and constellations, on the celestial sphere that are observable, at some time, to decrease from the stars of the entire celestial sphere to just the stars of the northern hemisphere of the celestial sphere.
5. The change in the altitude of P_n from 0° at the equator to 90° at the North Pole will cause the number of circumpolar stars and constellations to increase from no circumpolar stars at the equator to the point at the North Pole where all the stars and constellations that are visible are also circumpolar.

Observations from the terrestrial southern hemisphere will duplicate those from the terrestrial northern hemisphere with few exceptions other than changes in the terms. In the southern hemisphere, P_s will serve the same function that P_n serves in the northern hemisphere. Circumpolar stars will be seen moving clockwise above the south point of the observer's horizon; seasonal constellations will be seen moving counterclockwise toward the north of the observer's horizon and the stars will rise and set at an angle toward the north.

Because of the number of constellations that had been created on the celestial sphere and the great number of stars that were contained within each constellation, the need for a classification system developed. The stars within a constellation are today identified and differentiated by a system that was introduced by Johann Bayer (1572-1625) of Augsburg, Germany. Bayer published a celestial atlas that included 60 constellations. He called the brightest star in the constellation "alpha," the second brightest star "beta," the third "gamma," and so on through the 24 letters of the Greek alphabet. After the Greek alphabet was exhausted, the letters of the Roman alphabet were used. In order to distinguish the alphas from one another, he added the constellation name in the Latin possessive (genitive) case. One unfortunate exception to this rule is the case of Ursa Major, which is undoubtedly the most recognized constellation in the northern hemisphere of the celestial sphere. In this constellation the stars were listed in a sequential order that ends at the tip of the handle.

Table 2 lists the letters of the Greek alphabet. Figure 13 illustrates the normal star identification method that is used on star maps. Figure 13 also illustrates the Ursa Major exception. Appendix 1 lists the 88 International Astronomical Union constellations, their Latin genitives and meanings.

TABLE 2
The Greek Alphabet

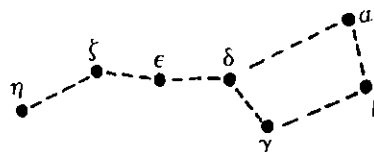
Alpha	α	Iota	ι	Rho	ρ
Beta	β	Kappa	κ	Sigma	σ
Gamma	γ	Lambda	λ	Tau	τ
Delta	δ	Mu	μ	Upsilon	υ
Epsilon	ϵ	Nu	ν	Phi	ϕ
Zeta	ζ	Xi	ξ	Chi	χ
Eta	η	Omicron	o	Psi	ψ
Theta	θ	Pi	π	Omega	ω

URSA MINOR



Rule by brightness

URSA MAJOR



Exception—sequential

Figure 13. The designation of stars by brightness and constellation.

The unequal brightness of the different stars on the celestial sphere is apparent to even the most casual observer. The Greek astronomer Hipparchus of Pontus, 4th century B.C., was the originator of a classification scheme that divided the stars into groups of magnitudes, that depended upon naked eye estimates. Hipparchus assigned the numbers from one to six to approximately one thousand stars. A sixth magnitude star was at the limit of naked eye visibility.

The development of the telescope revealed stars that were invisible to the naked eye. This necessitated an expansion of the lower part of scale to larger and larger numbers. The visual limiting magnitude, on this scale, of the 200 inch telescope at Mount Palomar is +20. The upper limit of the scale was extended into negative numbers in order to more accurately include the brighter stars and planets. The brightest object on this part of the apparent magnitude scale (m_v) is the closest star, our sun, at magnitude -26.7.

The eye is sensitive to the ratio of the brightness between two stellar objects and not to any absolute difference in their brightness. A difference of 5 in magnitude (i.e. from $m_v = 1$ to $m_v = 6$) was estimated to correspond to a ratio of 100 in brightness. In 1856, a ratio of 2.512, the fifth root of 100, was adopted as the standard ratio between a one magnitude interval (i.e. from $m_v = 1$ to $m_v = 2$ or from $m_v = 3$ to $m_v = 4$). The ratio of brightness for a two magnitude difference would be $(2.512)^2$ or 6.3. A three magnitude difference would represent a brightness ratio of 16.

The apparent magnitude system of Hipparchus is still in use today, though the naked eye estimates have been replaced by photoelectric and photographic methods which provide more accurate measures. The apparent magnitudes of stars are conveniently represented on star charts by circles of different sizes. The larger circles usually represent the brighter stars. Table 3 lists several stars and their apparent magnitudes. The decimals are used to differentiate between the brightness of stars that are within one magnitude class.

TABLE 3
Apparent Magnitudes of Selected Stars

Star Name	Designation	Apparent Magnitude
Sirius	α Canis Majoris	-1.42
Arcturus	α Boötis	-0.06
Vega	α Lyrae	+0.04
Betelgeuse	α Orionis	+0.41
Pollux	β Geminorum	+1.16
Polaris	α Ursae Minoris	+1.99

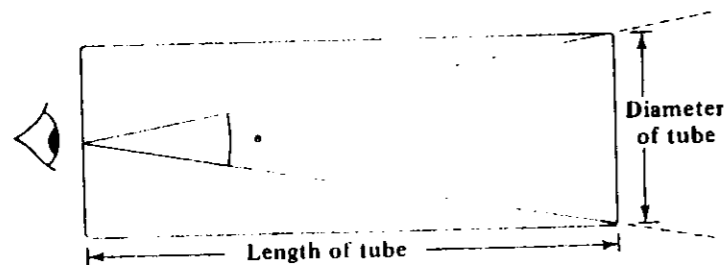


Figure G. Cardboard tube viewer.

$$\text{Tangent } (1/2\theta) = \frac{1/2 \text{ diameter of tube}}{\text{length of tube}}$$

The angle $1/2 \theta$ can also be determined graphically by drawing a full sized diagram of the cardboard tube and measuring the angle with a protractor.

The area of the celestial sphere, in square degrees (a) seen through the cardboard tube can be calculated using the value obtained for $1/2 \theta$.

$$\text{Area viewed (a)} = \pi (\text{Radius})^2 = \pi (\theta/2)^2$$

The total area of the celestial sphere in square degrees (A), can be determined.

$$\text{Area of a sphere} = 4\pi(\text{Radius})^2$$

$$\begin{aligned} \text{From the circumference of a circle: } 2\pi(\text{radius}) &= 360^\circ \\ \text{radius} &= \frac{360^\circ}{2\pi} = \frac{180^\circ}{\pi} \end{aligned}$$

$$\text{Therefore: } A = 4\pi(180^\circ/\pi)^2 = 41,253 \text{ square degrees}$$

The total number of tube areas (N) that would be required to cover the entire celestial sphere can be calculated.

$$\begin{aligned} \text{Number of tube areas} \\ \text{on celestial sphere (N)} &= \frac{\text{Area of sphere (A)}}{\text{Area of tube (a)}} \end{aligned}$$

$$N = A/a$$

Let (Σ) be equal to the average number of stars viewed through the tube over different areas of the sky. The approximate number of stars visible on the celestial sphere will be equal to the product of the average number of stars (Σ) seen through the tube and the total number of tube areas (N) on the celestial sphere.

$$\begin{aligned} \text{Approximate number of stars} \\ \text{visible on celestial sphere} &= \Sigma \times N \end{aligned}$$

Use the trigonometric or graphic method to determine the area (a) in square degrees that is seen through your cardboard tube. Count the stars seen through the tube over several different areas of the sky. Calculate the average number of stars (Σ) seen through the tube. Calculate the approximate number of stars visible on the celestial sphere. Determine the magnitude of the faintest star visible and compare your estimate with Table 4.

How could you account for the discrepancies in the counts between observers on the same evening? How could you account for discrepancies in the counts during different seasons (assume same transparency)? How could you account for discrepancies in the counts for observers at different latitudes (assume same transparency)?

Neanderthal man saw a different winter sky

By GEORGE REED

Seventy-five thousand years ago parts of the earth were inhabited by a heavily muscled creature who stood five feet tall. This man-like being, called Neanderthal man, is known today by the numerous fossils he left behind.

It is known, for instance, he lived around the rim of the Mediterranean Sea and throughout parts of Europe. It is also known he used fire, constructed a variety of tools and went out of his way to hunt 1,500 pound cave bears.

Neanderthal man is the most thoroughly studied primitive ancestor of the modern day homo sapien. The Neanderthals, in all probability, were also the first of our ancient ancestors who had the intelligence and leisure time to begin to look at the night sky with more than a sense of awareness. They were probably the first true astronomers.

What did the winter sky look like to a Neanderthal stargazer? In some ways it was quite different from the sky we see on winter nights. This is because the stars in space are constantly moving around. We don't notice the effects of this motion within short time intervals because of the great distances of the stars. Changes in the positions of the stars only become obvious over long time intervals.

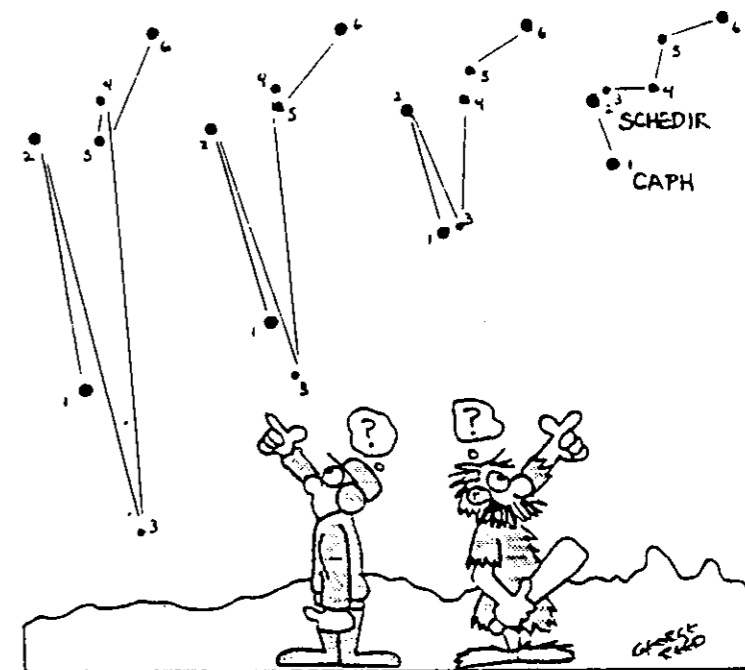
Dr. Robert Doyle, a Professor of Astronomy at Frostburg State College, in Maryland, recently calculated the positions of nearly 300 bright stars as they would have been seen by the Neanderthal astronomer. The results indicate some parts of the Neanderthal night sky would be almost unrecognizable today, while other parts would be significantly different, but still substantially recognizable.

The northern circumpolar area of the Neanderthal sky would appear the most different to us today. The famous "w" of the constellation Cassiopeia did not exist then. Its stars would be spread out into the areas occupied by other constellations today. The Cassiopeia stars did not move into the "w" arrangement until nearly 25,000 years ago. The Big Dipper was recognizable 75,000 years ago but it was not shaped the way it is seen today.

Two of today's bright seasonal stars were circumpolar stars in the Neanderthal sky. The bright star Capella in the constellation Auriga, the Charioteer, is a winter star now. It is also the fourth brightest star visible from mid-

THE STARS OF CASSIOPEIA IN FEBRUARY

75,000 B.C. 50,000 B.C. 25,000 B.C. 1979 A.D.



northern latitudes and the sixth brightest star to be seen from anywhere on earth. Seventy-five thousand years ago it was a circumpolar star and the third brightest star seen from anywhere on earth.

The bright springtime star Arcturus, in the constellation Bootes the Hunter, is the second brightest star we can see today from the mid-northern latitudes. It was a circumpolar star in the Draco the Dragon region and the seventh brightest in the Neanderthal sky. The brightness of several stars has changed because of changes in their distances from us over the last 75,000 years.

The winter sky in the south would also have changed. In Neanderthal times, Orion would look pretty much the same as it does today. Some of the other bright stars, however, were in substantially different positions. Sirius, the brightest star in our night sky, then and now, was seen higher in the sky. The same is true of Procyon, the brightest star of Canis Minor. Procyon, instead of Pollux, would have appeared as a twin star with Castor. Pollux was farther west of its present position. Aldebaran, the red eye of Taurus the Bull would also have moved. Instead of appearing in front of the Hyades star cluster, Aldebaran would have been north of the cluster. The increase in the distance of

Aldebaran, from 54 light years to 68 light years from the sun, has caused a corresponding decrease in its brightness. Aldebaran went from the fifth brightest to the ninth brightest star that can be seen from mid-northern latitudes.

Our awareness of the changes in the positions of the nighttime stars and our ability to measure these small changes is a rather recent accomplishment. Edmond Halley first announced his discovery of the slowly changing positions of the stars in the early 18th century. Today with the aid of calculators, computers and a vast quality of precision observational data, it is possible for us to see the skies as they were seen in the past, and the skies as they will be seen in the future.