Chapter 2 The Earth and the sky

2.1 *Imaginary* Celestial sphere

For objects very far away from us, they appear to be of equal distance from us (Fig. 2-1). It is in fact an illusion. Look at the following example:

Suppose you are standing under the City Wall, and looking at a far-way tower on the wall (Fig. 2-1 Top). Mr. A and Mr. B are now standing near to the tower (Fig. 2-1 Bottom). Although Mr. A is nearer and Mr. B is farther away from you, they seem to be of the same distance from you. Both are too far for you to tell the distance easily.

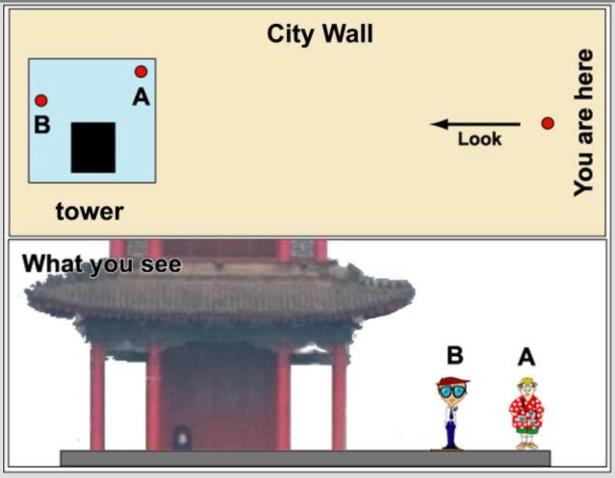


Fig. 2-1: (Top) Imagine that you stand on the City Wall, and two persons, Mr. A and Mr. B, stand near a far-away tower. (Bottom) They seem to be at the same distance from you.

- ✓ Similarly, since all stars are extremely far away from us, they appear to be of the same distance from us. It seems that we are at the centre of a huge imaginary sphere, the stars are attached to the surface of that sphere — **celestial sphere** (天球). (Fig. 2-2)
- ✓ All celestial bodies are *imagined* to attach to the inside of a very large hollow sphere surrounding the Earth.
- ✓ This is a convenient model of the sky for mapping the *apparent positions* and *motions* of celestial bodies as seen from Earth.

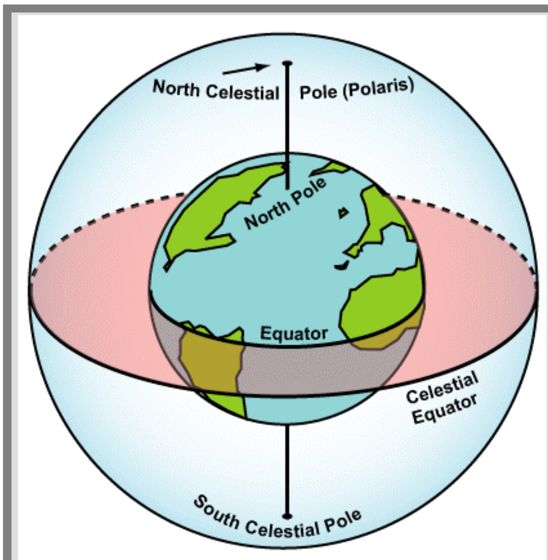


Fig. 2-2: The celestial sphere models the appearance of the sky.

In order to define the positions of stars on the celestial sphere, one can specify the coordinates of a star by using the equatorial coordinate system [1]

- ✓ **Declination** (DEC, δ) and **Right Ascension** (RA, α), which are similar to latitude and longitude on Earth respectively (Fig. 2-3).

- ✓ DEC is measured in degrees: $0 \le \delta \le 90^o$ for northern celestial hemisphere; $-90^o \le \delta \le 0$ for southern celestial hemisphere.

- ✓ RA counts from the **vernal equinox**（春分點） eastward. One should assume vernal equinox is a *fixed point* on the celestial sphere at this moment.[2] RA is measured in hours, minutes, and seconds.

  24 hr = 360°, or 1 hr = 15°

  1 hr = 60 min

  1 min = 60 sec

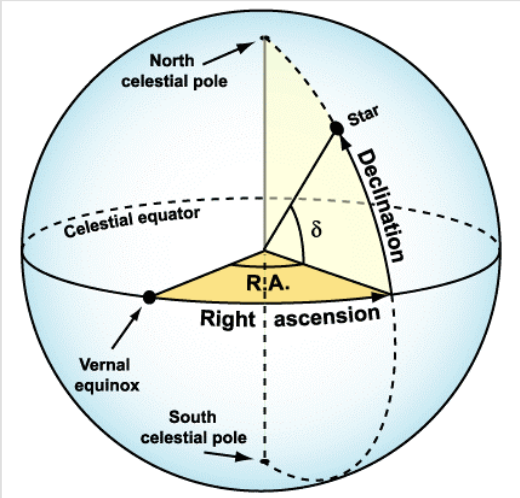


Fig. 2-3: The coordinates of a star are defined by Declination (DEC, δ) and Right Ascension (RA, α).

- ✓ *Apparent sizes* and *separations* of celestial bodies are measured in angles:

  1 circle = 360° (degrees),

  1° = 60′ (arc minutes, or minutes of arc),

  1′ = 60″ (arc seconds).

  For example, apparent diameters of the Sun and Moon is about 0.5°,[3] the width of a finger at arm′s length about 1° and that of the fist at arm′s length about 10° (Fig. 2-4).

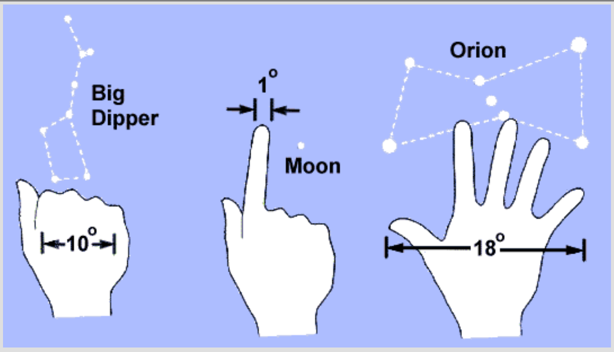


Fig. 2-4: Your hand held at arm′s length makes a convenient measuring tool.

[1] See Box 2.1 for discussion about celestial coordinate systems.
[2] See Section 2.6 for the definition of the vernal equinox.
[3] Due to this coincidence of nature and also the orbits being elliptical, there are two possible types of solar eclipses (total and annular) when the Moon is along the line of sight to the Sun.

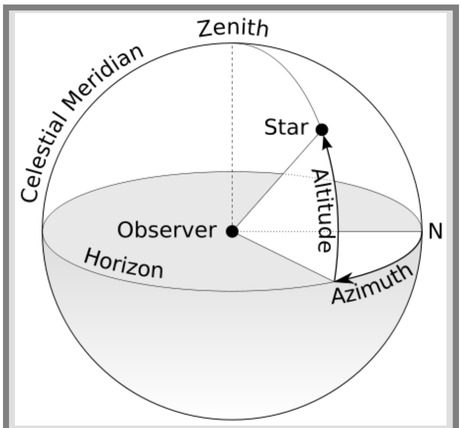
If the Earth were not spinning (rotate about its own axis), we would always see a stationary celestial sphere, i.e., all the stars on the celestial sphere will not move. However, it is definitely not true. Our Earth does self-rotate! Because of the self-rotation (once a day) of the Earth, the celestial sphere appears to rotate once a day, so one may define:

- ✓ **Celestial poles:** The north (N) and south (S) celestial poles (Fig. 2-3) of the celestial sphere located, respectively, above the north and south poles of the Earth. The poles specify the axis of daily rotation of the celestial sphere.
- ✓ **Polaris** (北極星) is a bright star close to the north celestial pole, so Polaris appears *almost* stationary during the daily rotation.
- ✓ **Celestial equator:** It is an imaginary plane, which divides the celestial sphere into the north and south hemispheres. (Fig. 2-3)

Box 2.1 Celestial coordinate systems

Besides the equatorial coordinate system (RA & DEC), two other commonly used systems are the *horizon coordinate system* (based on the observer's horizon), and the *galactic coordinate system* (based on the galactic plane). Here we will discuss the former one.

The point directly above an observer is known as the **zenith** (天頂). **Altitude** (ALT) is the angle measured from the horizon to a celestial object (say, a star), towards the zenith. **Azimuth** (AZ) is the angle measured eastward from the north along the horizon circle.



The horizon coordinate system. (Image: Wikipedia Commons)

While the horizon coordinate system is simple to define and useful for stargazing, it has significant shortcomings. The horizon coordinates of celestial objects depends on the location of the observer. Another problem is that the coordinates continue to change due to the self-rotation of the Earth. Not to mention that the orbital motion of the Earth causes the coordinates to shift slightly every day. Because of all these complications, we would focus on the equatorial coordinate system in this course.

For the conversion between the two coordinate systems, see the excellent explanation by Prof. J. Kaler on http://www.stargazing.net/kepler/altaz.html

2.2 Daily motion (周日運動)

We know that the Earth is not stationary, but *self-rotating* (自轉) from West (W) to East (E), i.e., counter-clockwise as seen from above the North Pole. The spinning/self-rotation of the Earth introduces much complication. Before we discuss the self-rotation of the Earth, let us talk about several phenomena first.

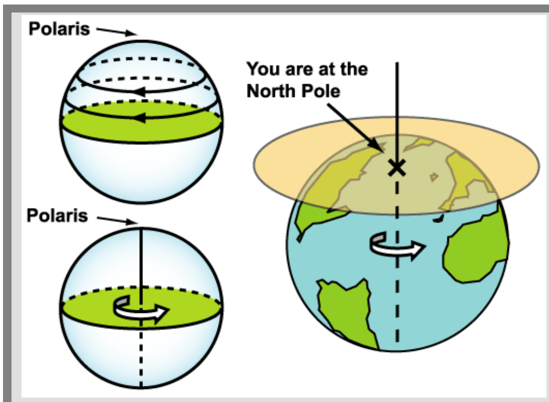


Fig. 2-5: At the North Pole, Polaris locates directly above you. (Right) Because of the self-rotation of the Earth (Left Bottom), the celestial sphere, which carries all stars, appears to move in counter-clockwise horizontally. (Left Up)

- ✓ Imagine that you are at the North Pole of the Earth, the polar star Polaris then locates directly above you. All stars appear to move on horizontal circular paths in counter-clockwise. (Fig. 2-5)
- ✓ At the South Pole of the Earth, Polaris locates directly under you. You see all stars are moving on horizontal circular paths but in clockwise direction (Fig. 2-6).

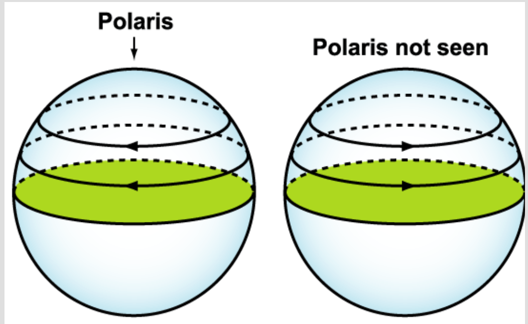


Fig. 2-6: At the North Pole, stars move in counter-clockwise horizontally; (Left) whereas at the South Pole, stars move horizontally but in clockwise direction.

- ✓ At equator, Polaris locates at the northern horizon. (Fig. 2-7 Right) Because of the self-rotation of the Earth, the celestial sphere, which carries all stars, appears to move along vertical circles. (Fig. 2-7 Left)
- ✓ As mentioned previously, Polaris is close to the north celestial pole, it appears *almost* stationary. Stars near Polaris circulate around it anticlockwise. On the other hand, in the south hemisphere Polaris is below the horizon, so it can never be seen in the south hemisphere.

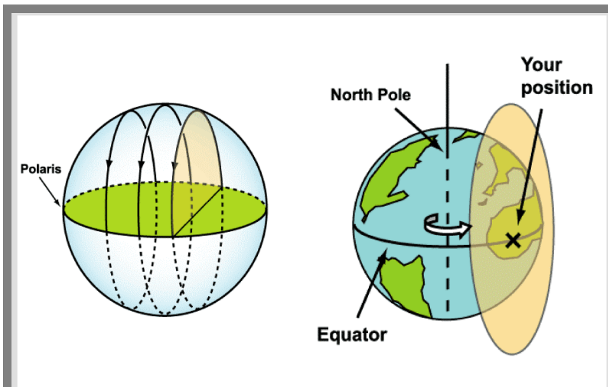


Fig. 2-7: At the equator, all stars appear to move along vertical circles because of the self-rotation of the Earth.

✓ No matter where the circular path is, the star always spend one day to complete one cycle since the Earth self-rotates once a day. This daily circular motion is called the **Daily motion**（周日運動）of stars.

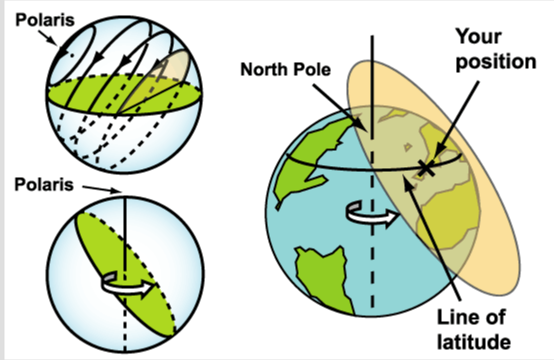


Fig. 2-8: At certain latitude, Polaris located at an angle above the horizon.

✓ Moreover, as the Earth is *self-rotating* (自轉) from West (W) to East (E), i.e., counter-clockwise as seen from above the North Pole, celestial bodies *appear* to move in opposite direction (E to W) in the sky, e.g., the Sun rises in the E and sets in the W.

✓ In general, at certain latitude (Fig. 2-8 Right), one see the polar star Polaris locates at an angle above the horizon (Fig. 2-8 Left Up). Because of the self-rotation of the Earth (Fig. 2-8 Left Bottom), the celestial sphere, which is carrying celestial bodies, rotate about the Polaris. (Fig. 2-8 Left Up)

✓ Position of Polaris depends on the observer location on the Earth, e.g., an observer at *north pole* sees Polaris directly overhead (Fig. 2-5); an observer at *equator* sees Polaris at the northern horizon (Fig. 2-7), or more generally (Fig. 2-9),

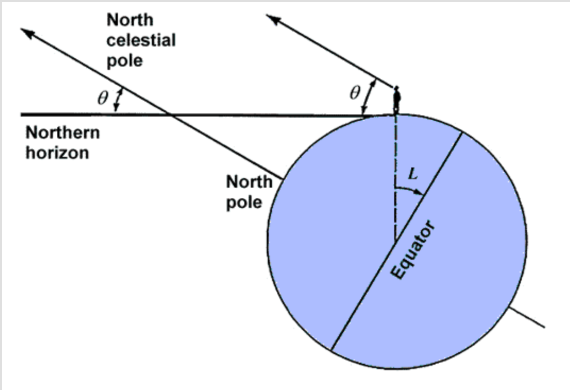


Fig. 2-9: For an observer at latitude L on the Earth, the N celestial pole is at an angle L above the northern horizon.

the angle of Polaris above the horizon = latitude of the observer

Can you verify if it is correct for an observer at one of the poles? How about an observer on the equator?

✓ Stars to be seen also depend on the *observer's location* on Earth. For example, observers at the North Pole can see stars of $\delta > 0$ only; Observers at equator can see all stars. Can you see why?

✓ Define a latitude L in the <u>northern</u> hemisphere as L N and in the <u>southern</u> hemisphere as L S, where $0 < L < 90$ degrees. Consider an observer located 24° N (Fig. 2-10), he can *never* see a star of $\delta < -66^\circ$, i.e., stars close to the S celestial pole never rises. On the other hand, he can *always* see a star of $\delta > 66^\circ$, i.e., stars close to the N celestial pole never sets. Stars that never rise or set are called **circumpolar star** (拱極星). (Fig. 2-11)

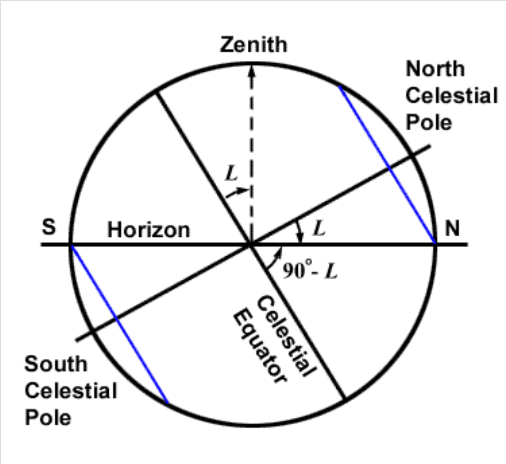


Fig. 2-10: Relation between the observer's latitude L and the part of the sky which is visible.

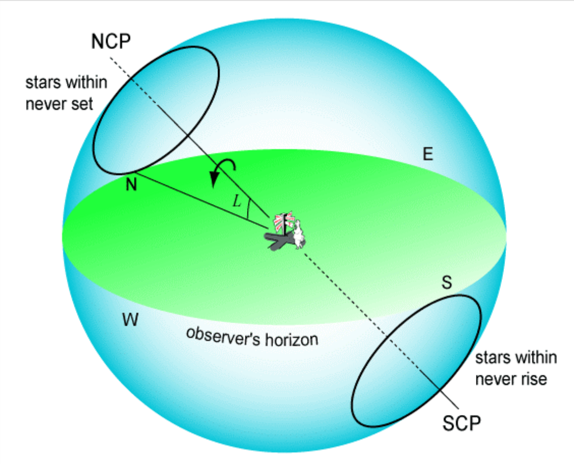


Fig. 2-11: Those objects below our horizon are invisible. Stars close to north celestial pole will never set, whereas those close to the south celestial pole will never rise.

2.3 Keeping track of Time

Suppose you are at latitude L, you see Polaris at an angle L above the northern horizon as discussed previously (Fig. 2-12). In addition, relative to an observer's horizon, one may define

✓ **Zenith** (天頂): the point directly overhead of the observer.

✓ **Meridian** (子午線)[4]: the great circle passing through the *north, south celestial poles* and the *zenith* of an observer. (Fig. 2-12)

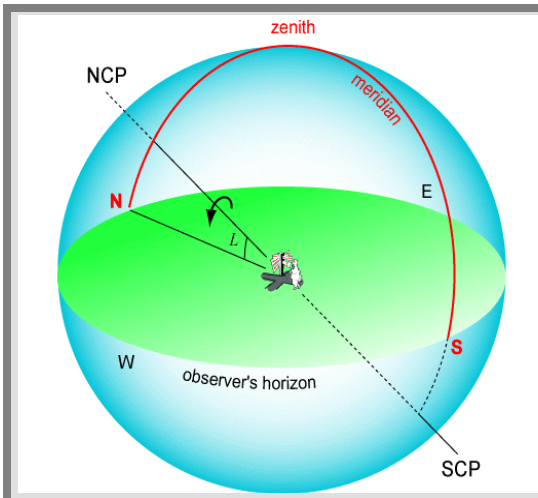


Fig. 2-12: Relative to an observer's horizon, the meridian is defined as a great circle passing through the north, south celestial poles and the observer's zenith.

[4] Not to be confused with a meridian on the Earth. In geography, a meridian refers to a half circle connecting the North Pole and the South Pole. Whenever we mention meridian in this note, we refer to *the* meridian in Astronomy.

Important: Since the zenith and meridian are defined with respect to an observer, so the zenith and meridian are *fixed* relative to the observer, even the celestial sphere (together with all stars) *rotates* once a day. (Fig. 2-13)

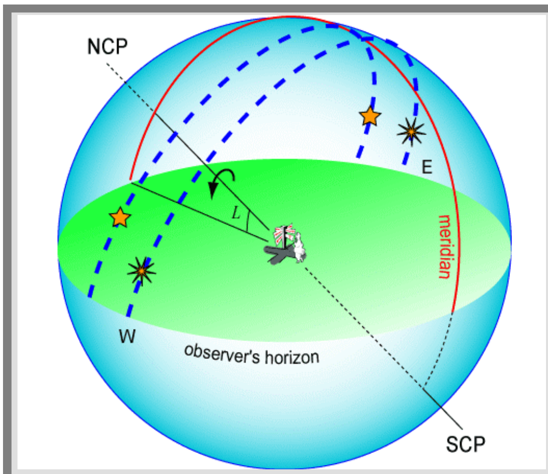


Fig. 2-13: Even all stars rotate once a day, the meridian is fixed relative to an observer.

In order to keep track of time, one may define

- ✓ **Hour angle** (H): Angle of a star (in hr, min, sec) measured from the observer′s meridian westward. H of a star increases with time from 0 to 24 hr as the celestial sphere rotates daily. For example, $H = 0$ when the star passes across the observer′s meridian.
- ✓ **Local sidereal time**（地方恆星時，LST）: The hour angle of the vernal equinox（春分點）relative to an observer at a given location. (Fig. 2-14) See Section 2.6 for details.

Question: RA of the bright star Regulus (軒轅十四) is 10h08m22.2s. Where is the star relative to an observer if the LST = 10h08m22.2s? (*Hint*: RA of a star is measured from the vernal equinox eastward.)

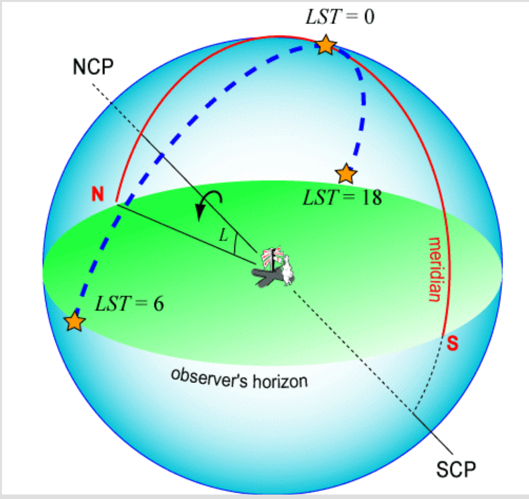


Fig. 2-14: The LST at the observation site is equal to the hour angle of the vernal equinox.

- ✓ **Sidereal day**（恆星日）: The time between successive passages of the vernal equinox across the observer′s upper meridian.[5] It is in fact equal to the self-rotation period of the Earth. So one may take any distant star (including the vernal equinox) to measure the length of a sidereal day.

[5] Depending on the observer's location and the time in the year, some celestial objects never raise and some other objects never set. Therefore it is important to distinguish between the two transits of the meridian.

Most observatories are equipped with a sidereal clock to measure LST, because LST is very convenient to keep track of celestial bodies. However, it is not convenient in our daily life. Traditionally we want the system of timekeeping used in everyday life to reflect the position of the Sun in the Sky. For example, thousands of years ago, the sundial was invented to keep track of the Sun. It is because the Sun's position determines whether we are awake or asleep and whether it is time for breakfast or dinner. Hence, it is quite obvious to define *apparent solar day* for time keeping.

✓ **Apparent solar day**: The time between two successive passages of the Sun across the observer′s meridian. Noon and midnight are defined, respectively, as the Sun crosses the upper and lower meridian. It is a timekeeping using the daily motion of the Sun.

However, the Sun is not a good timekeeper! It is because the length of an apparent solar day varies.

✓ After one sidereal day, the Earth has self-rotated once, but the Sun is not at the observer **A**′s meridian (Fig. 2-15). **A** has to wait for the Earth to self-rotated a bit more (estimate ~1°) to see another passage of the Sun across his meridian, so an apparent solar day is *slightly longer* than a sidereal day.

✓ To make it more complicated, the Earth's orbit is not a perfect circle, but an ellipse. The Earth moves slightly faster when closer to the Sun and slower when farther away from the Sun. As a result, the length of an apparent solar day varies from one time of a year to another! How can we design a clock to measure the apparent solar day?

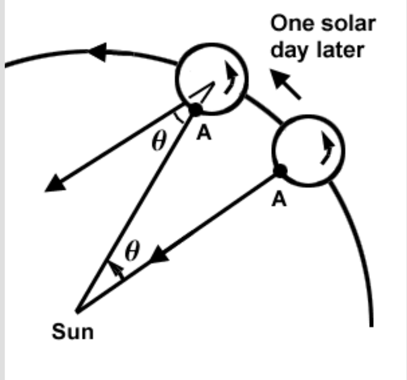


Fig. 2-15: Solar day and sidereal day. After one sidereal day, the Sun is not at the observer's meridian.

In order to avoid these difficulties, one may define

✓ **Mean sun**: It is an *imaginary* object that moves uniformly in a perfect circular orbit. One should see that the object sometimes ahead of the real Sun, sometimes behind.[6]

✓ **Mean solar day**: The time between two successive passages of the mean Sun across the meridian. It is *exactly 24 hours*. Our alarm clock or wristwatch measures mean solar day.

[6] Another way to see the effect is to record the location of the Sun at the same time throughout the year. The locations trace out a figure-8 pattern known as the analemma. See Ryden & Peterson 10 pages 21-22 for details.

Question: Find out the relation between **mean solar day** and **sidereal day**. Given that there are 365.2422 *mean solar days* in one year.

Solution: Suppose 1 solar day = S sidereal day ($S > 1$). In one mean solar day, the Earth has moved by an angle θ with respect to the Sun. In the same time interval, the Earth has self-rotated by $360^\circ + \theta$. (Fig. 2-15)

The angular speed of self-rotation: $\omega = \dfrac{360^\circ}{1}$ (sidereal day)$^{-1}$.

The angular speed of orbital motion:

$$\Omega = \frac{360^\circ}{365.2422}\ (\text{solar day})^{-1} = \frac{360^\circ}{365.2422\,S}(\text{sidereal day})^{-1}.$$

Therefore, $\omega S - \Omega S = 360^\circ$,

$$S = 1 + \frac{1}{365.2422} \approx 1 + 2.737909\times 10^{-3}\,\text{sidereal days}$$

We have, $\boxed{\textit{1 sidereal day = 23 hr 56 min 4.1 sec of mean solar time.}}$ Thus, it explains why a star rises at the eastern horizon 4 minutes earlier each day.

- ✓ **Universal Time (UT)** [7]: Mean solar time at Greenwich 格林威治 (a seaport just outside of London)
- ✓ **Time zones** are defined by meridians of longitude, each zone being 15° (1 hr) wide. Within a zone, it has the same **Standard Time**. This is what we use in our daily life.
- ✓ **Standard Time (ST)**: the mean solar time for a meridian of longitude at the centre of the zone. For example, China Standard Time = UT + 8 hour. (Fig. 2-16)

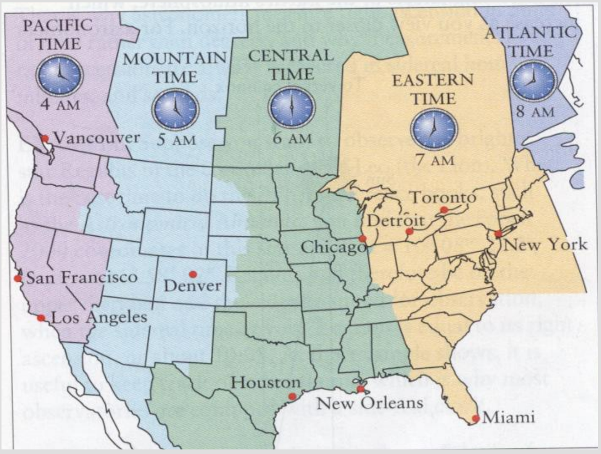


Fig. 2-16: Time Zones in North America.

[7] Strictly speaking, here we are referring to UT1, which is an astronomical time. The Coordinated Universal Time (UTC), on the other hand, is defined by atomic clocks. Due to the slowing down of the Earth's rotation (see Chapter 3), leap seconds are introduced to synchronize UT1 and UTC.

2.4 Constellations

- ✓ **Constellations:** Visual groupings[8] of stars (Fig. 2-17). While many ancient cultures had their own systems, over half of the 88 modern constellations are originated from the Greeks. Some constellations, e.g. Telescopium（望遠鏡座）, were added in modern days.

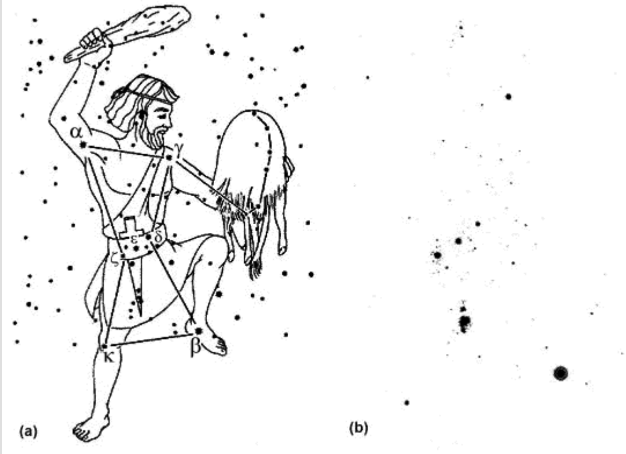


Fig. 2-17: The brightest stars Orion are connected to form the outline of a hunter.

- ✓ The names of stars were assigned as Greek letters to stars in order of brightness, i.e., α is the brightest star in a constellation, β the next brightest, etc., e.g., Sirius (天狼星) is known as α Canis Major (大犬座).

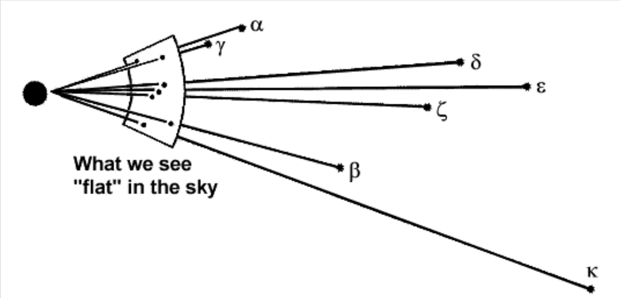


Fig.2-18: The true 3-dimensional spatial locations of the stars in Orion. Stars in the constellation are actually very far away from each other. They just appear to be in about the same direction as seen from the Earth.

- ✓ Usually *no real correlation* among the stars in the same constellations, they could be very far away from each other (Fig. 2-18).
- ✓ They rise and fall with the rotation of the celestial sphere.
- ✓ The constellations one can see depend on the observer's location and season. For example, an observer living in the northern hemisphere can never see some southern constellations (they never rise above the horizon), but he/she can always see some constellations around the NCP as they never set.

[8] Nowadays, the 88 "official" constellations are actually defined by their boundaries instead of patterns. For the origin of the constellations, see http://www.iau.org/public/constellations/ .

2.5 Apparent motions of the Sun

- ✓ **Daily motion**: The Sun moves across the sky daily because of the self-rotation of the Earth. The celestial sphere rotates *together with* the Sun and all the stars *once a day*.
- ✓ **Yearly motion:** Because the Earth revolves around the Sun, the Sun appears to drift *eastwards* of the celestial sphere slowly throughout a year. As a result, the Sun moves across the background of stars on the celestial sphere, passing through 13 constellations, completing a path called the **ecliptic**（黃道）. (Fig. 2-19)

At night, we can only see constellations at the **opposite** side of the Sun, e.g., we can see Gemini (雙子座) in January, but *not* Sagittarius (人馬座).

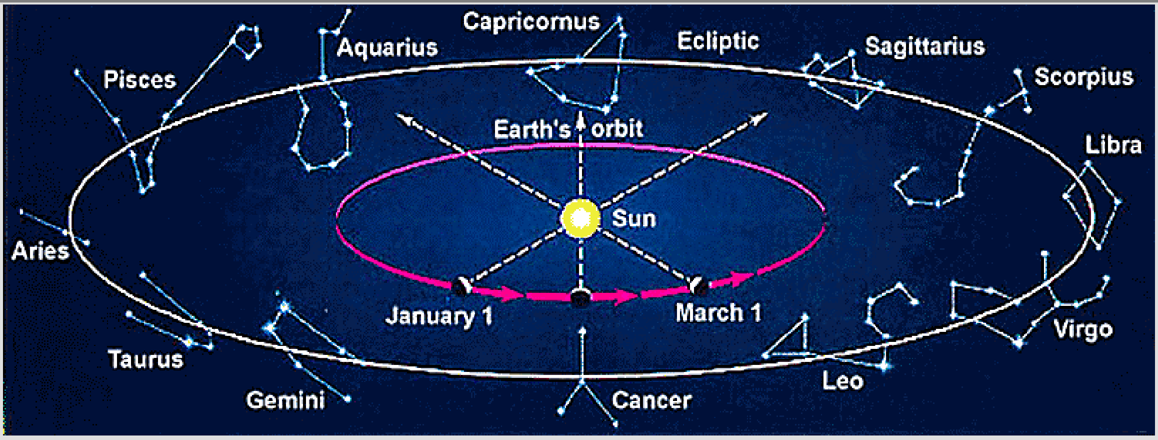


Fig. 2-19: As the Earth moves in its orbit, we see the Sun in front of different constellations. In January the Sun is in front of Sagittarius, but by March it has moved along the ecliptic to Aquarius. The ecliptic is the projection of the Earth's orbit onto the celestial sphere.

2.6 Seasons and the calendar

✓ The Earth's equatorial plane is not parallel to its orbital plane around the Sun, but it makes an angle of 23.5° with the orbital plane (Fig. 2-20). On the Earth we observe that the Sun appears to drift slowly in the celestial sphere once a year, and the ecliptic makes an angle of 23.5° with the celestial equator (Fig. 2-21)

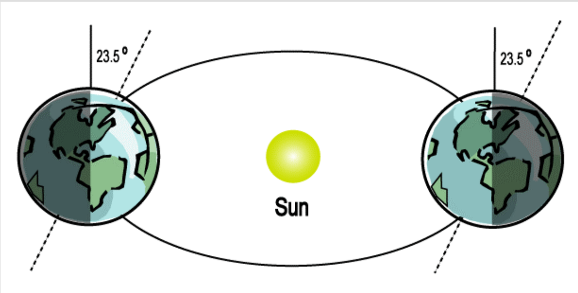


Fig. 2-20: The Earth's equatorial plane is not parallel to its orbital plane around the Sun, but it makes an angle of 23.5°.

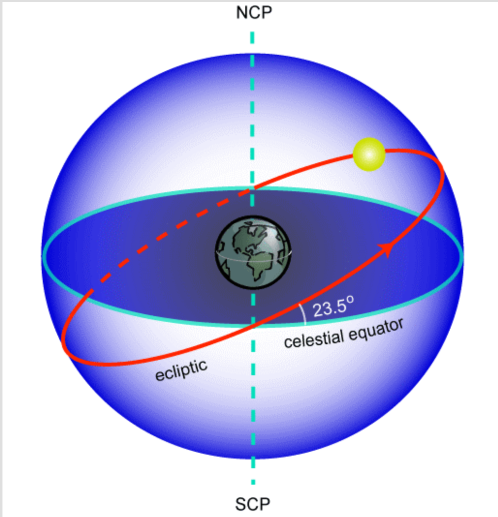


Fig. 2-21: The ecliptic makes an angle of 23.5° with the celestial equator.

✓ Four locations along the ecliptic defining the seasons (Fig. 2-22):

Vernal equinox (春分) 21/3**:** The point where the Sun crosses the celestial equator moving *northward*.

Summer solstice (夏至) 22/6**:** The Sun is farthest North, and it makes an angle 23.5° with the equatorial plane northwards.

Autumnal equinox (秋分) 23/9**:** The point where the Sun crosses the celestial equator moving *southward*.

Winter solstice (冬至) 22/12**:** The Sun is farthest South, and it makes an angle 23.5° with the equatorial plane southwards.

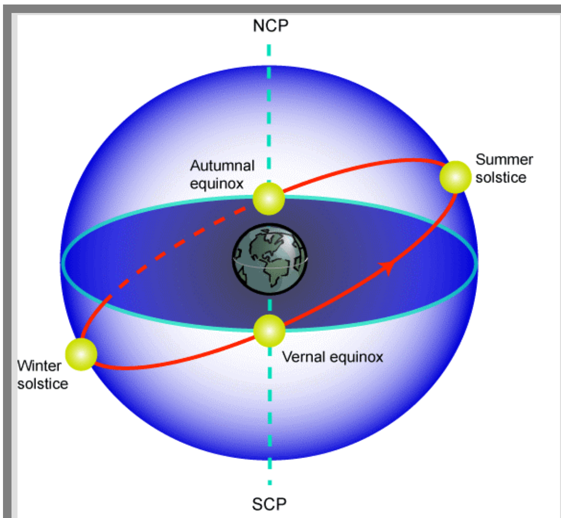


Fig. 2-22: Following the ecliptic (dashed line), the Sun crosses the celestial equator at equinoxes. The solstices mark the Sun's most northerly and most southerly points.

Do you notice that there is longer daytime in summer in North hemisphere? In fact, the inclination of the Earth's rotation axis is the main reason for seasons.

- ✓ When the Sun travels to summer solstice, sunlight comes from the north of the equatorial plane at the greatest angle 23.5°, so and it has the *longest daytime* in the Northern hemisphere, but the *shortest daytime* in the Southern hemisphere. (Fig. 2-23)

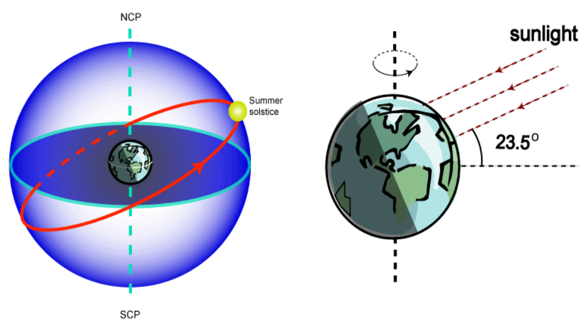


Fig. 2-23: In summer solstice, it has the longest daytime in the Northern hemisphere, but the shortest daytime in the Southern hemisphere.

- ✓ When the Sun travels to winter solstice, sunlight comes from the south of the equatorial plane at the greatest angle 23.5°, and it has the *shortest daytime* in the Northern hemisphere, but the *longest daytime* in the Southern hemisphere. (Fig. 2-24)

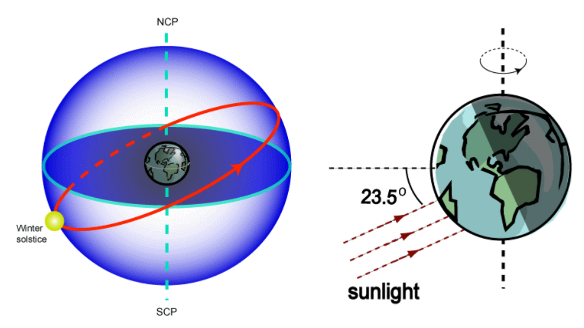


Fig. 2-24: Similarly, in winter solstice, it has the shortest daytime in the Northern hemisphere, but the longest daytime in the Southern hemisphere.

Question: Can you guess how long of the daytime at the equator, when the Sun travels to summer or winter solstice, vernal or autumnal equinox?

Summer and winter

- ✓ At noon on the day of the summer solstice, the Sun shines from nearly overhead in Northern hemisphere. Like the light from a flashlight shinning nearly straight downward, the summer sunlight is not spread out very much (Figure 2-25a). On the day of the winter solstice, sunlight strikes the ground at a steep angle and spreads out in Northern hemisphere (Figure 2-25b). Thus, the ground receives less energy per square meter from the winter Sun than from the summer Sun. Hence, it is hotter in June than in December in Northern hemisphere. But why is it hotter in December in Australia?

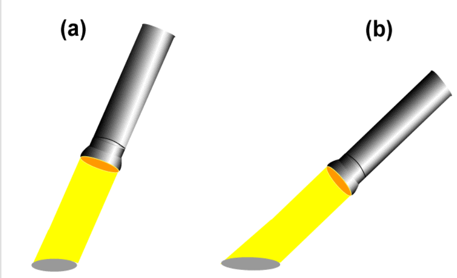


Fig. 2-25: The spreading of light. (a) The light from a flashlight shinning nearly straight downward. Like the summer sunlight is not spread out very much. (b) The light strikes the ground at a steep angle and spreads out. Thus, the ground receives less energy per square meter from the winter Sun than from the summer Sun.

Sun rise and set

- ✓ Because the Earth revolves around the Sun, the Sun appears to drift along the **ecliptic** on the celestial sphere slowly throughout a year. (Fig. 2-26)
- ✓ When the Sun is at *vernal equinox* (or autumnal equinox), because of self-rotation of the Earth, the Sun appears to move along the celestial equator. (Fig. 2-27)

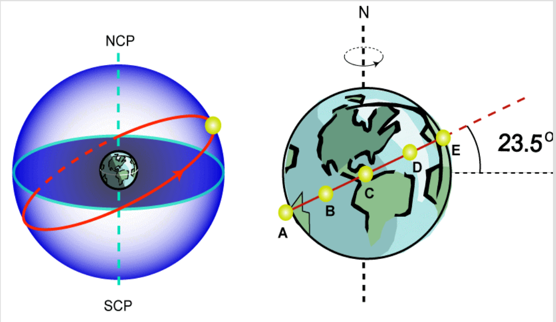


Fig. 2-26: The Sun appear at positions A to E when the Sun is moving from *winter solstice* (A) to *vernal equinox* (C) to *summer solstice* (E).

Question: Where does the Sun move along as observed at equator?

Solution: At equator, i.e., latitude of 0°, the Sun is moving along a vertical circle from the east to west.

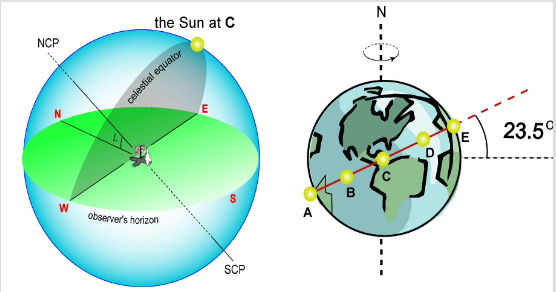


Fig. 2-27: When the Sun is at *vernal equinox* (C), the Sun appears to move along the celestial plane.

- ✓ When the Sun is positions from C (*vernal equinox*) to E (*summer solstice*), the Sun appears to move in a plane parallel to the celestial plane, but shifting northward (Fig. 2-28); Similarly, when the Sun is positions from A (*winter solstice*) to C (*vernal equinox*), the Sun appears to move in a plane parallel to the celestial plane, but shifting northward (Fig. 2-29).
- ✓ After summer solstice, the Sun appears to move along the celestial plane, but shifting southward.

Question: How does the Sun move as observed at the equator?

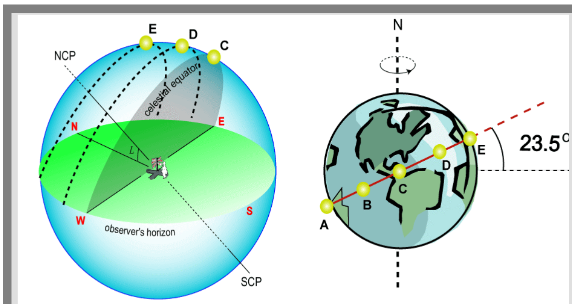


Fig. 2-28: When the Sun is travelling from positions C (*vernal equinox*) to E (*summer solstice*), the Sun appears to move in a plane parallel to the celestial plane, but shifting northward.

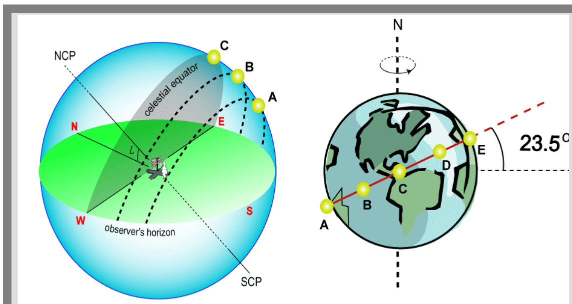


Fig. 2-29: When the Sun is travelling from positions A (*winter solstice*) to C (*vernal equinox*), the Sun appears to move in a plane parallel to the celestial plane, but shifting northward.

Calendar

- ✓ **Tropical year**: The time required for the Sun to return to the vernal equinox, about 365.2422 mean solar days, so one added Feb.29 to every calendar year that is divisible by four, i.e., 366 days. But it still produces an error of about 3 days in every 400 years!
- ✓ Only the century years divisible by 400 are leap years (29 days in Feb). For example, 1700, 1800, and 1900 were *not* leap years; the year 2000 is a leap year. This is the **Gregorian calendar**, which we use now. But it still produces an error of about 1 day in every 3300 years!!
- ✓ **Julian calendar**: Still used in Astronomy and computer programming.[9] A Julian year is defined to be exactly 365.25 days.

[9] One usage is for defining the *epoch*. Due to the precession of the Earth's axis (Section 2.9) and other perturbations, the celestial coordinates change over time. It is therefore important to specify when the coordinate is measured. A Julian epoch is named with a prefix J, and the Julian year. The current standard is J2000.0 epoch.

2.7 Brightness of celestial bodies

- ✓ **Magnitude scale**: *lower magnitude of a star, brighter it is*, e.g., a star of magnitude one is brighter than that of magnitude two, etc.
- ✓ Magnitude is a measurement of light intensity B (light energy received per unit time per unit area). The magnitude m difference of star X and star Y is defined by the log scale:

  $$m_1 - m_2 = -2.5\log_{10}(B_1/B_2),\ \text{or}\ B_1/B_2 = 10^{-0.4(m_1-m_2)}$$

  Each magnitude differs by an intensity ratio of $\sqrt[5]{100} \approx 2.512$. For example, a magnitude one star is about 2.512 times brighter than a magnitude two star; the intensity ratio is then about 100 times for two stars with magnitude difference of five.
- ✓ **Apparent magnitude**（視星等，m）: Magnitude as measured on the Earth (Fig. 2-30), we have $m = k - 2.5\log_{10} B$, where k is a constant fixed by assigning a magnitude to a particular star. As convention, $m = 0$ for Vega (織女星). *Closer* objects look *brighter*, and *farther* objects look *dimmer*, e.g., a close candle may appear brighter than a far street lamp. Therefore, apparent magnitude does *not* give a measure of the *luminosity*（光度）of a celestial body, but *only* measures its brightness（亮度）, i.e., the amount of light energy (per unit time per unit area) *received on Earth*.

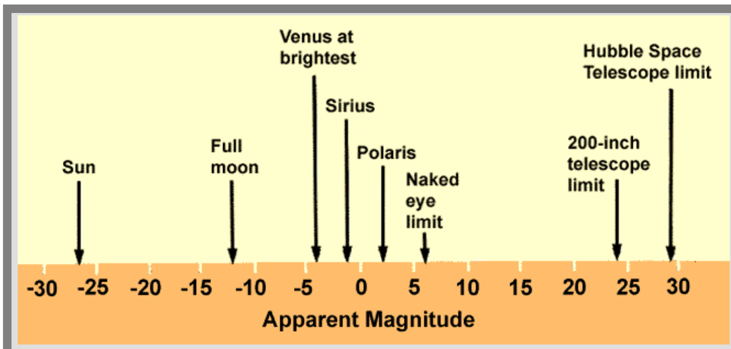


Fig. 2-30: The scale of apparent visual magnitudes extends into negative numbers to represent the brighter objects. The Sun has an apparent magnitude of about -27; it is the brightest celestial object as seen from the Earth.

- ✓ **Absolute magnitude**（絕對星等，M）: Magnitude as if all stellar objects *were* placed at a distance of 10 pc from the Earth. Absolute magnitude measures the luminosity of a celestial body, which is the amount of light energy per unit time *emitted by the body*.

2.8 Planets

- ✓ Planets move around the Sun in nearly circular orbits, *except* Mercury.
- ✓ They do *not* emit light, they shine by reflecting sunlight
- ✓ Their orbits lie on nearly the *same plane* as the Earth′s. (Fig. 2-31) Therefore, planets *appear* to move near the ecliptic. They all move within the **zodiac** (黃道帶), a band of width 18° centred on the ecliptic.
- ✓ Planets closer to the Sun move faster and have shorter orbital periods. For example, the period of the Earth = 1 year, that of Mars ≈ 1.9 year, and that of Saturn ≈ 29 year.
- ✓ Inner planets (Venus and Mercury) are closer to the Sun than the Earth. They can be observed for a short time just *after sunset* as **evening stars** above the *western* horizon, or just *before sunrise* as **morning stars** above the *eastern* horizon.

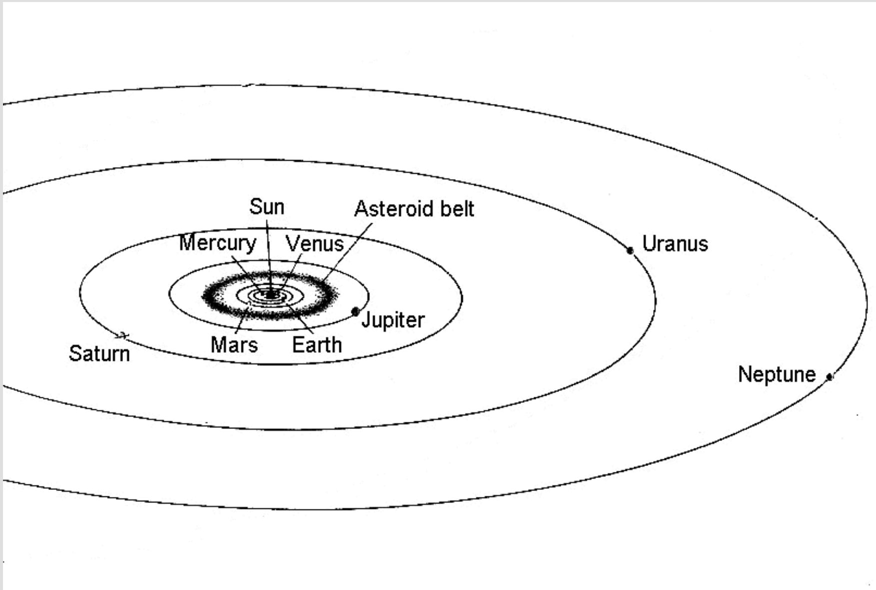


Fig. 2-31: The Solar System. The planets revolve around the Sun in nearly circular orbits. Their orbital planes lie almost on the same plane.

2.9 Precession

- ✓ The Pole star is changing. The Earth's rotation axis currently points towards the star Polaris. Thuban, also known as α Draco（天龍座α）, was the Pole star 5,000 years ago. The axis will point to Vega 12,000 years later (Fig. 2-32).

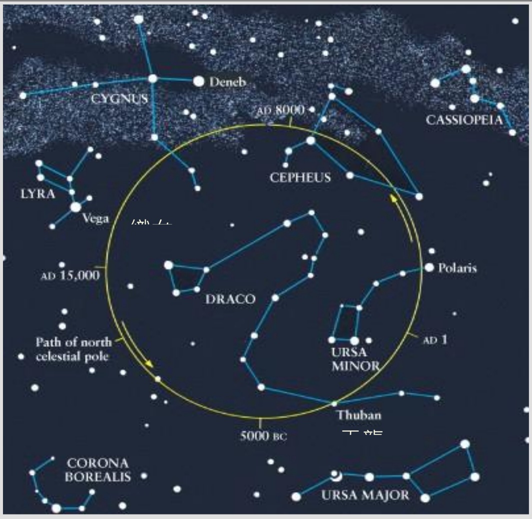


Fig. 2-32: The direction of the Earth′s rotation axis is changing very slowly.

- ✓ Nevertheless, the *precession* of the Earth's axis is very slow. It takes about 26,000 years per cycle. Because the Earth is not a perfect sphere, the gravity of the Moon and the Sun will produce torques on the Earth. It is similar to the precession of the spinning top. (Fig. 2-33)
- ✓ In addition, this precession causes the difference between a sidereal year and a tropical year.[10] The Earth orbits the Sun once for every roughly 365.26 days, which is equal to one sidereal year.

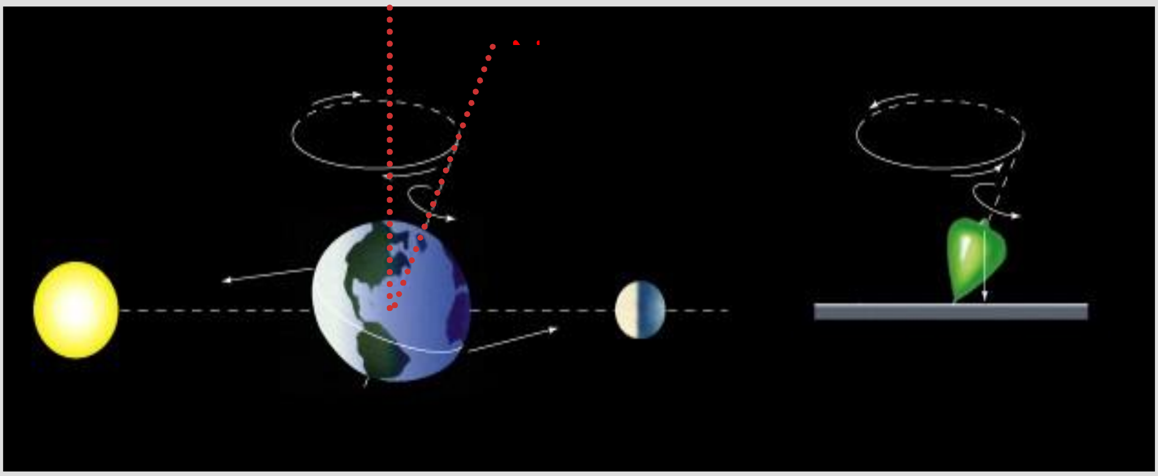


Fig. 2-33: The gravity of the Moon and the Sun produce torques on the Earth. It causes the precession of the Earth′s rotation axis (Left). It is similar to the precession of the spinning top. (Right)

[10] See Roy & Clarke, *Astronomy: Principles and Practice (4th ed.)*, 2003, Sections 9.7 and 11.12