Chapter 2

The Earth and the sky

The Earth and the sky

2.1 Imaginary Celestial Sphere

2.2 Daily motion

2.3 Keeping track of Time

2.4 Constellations

2.5 Apparent motions of the Sun

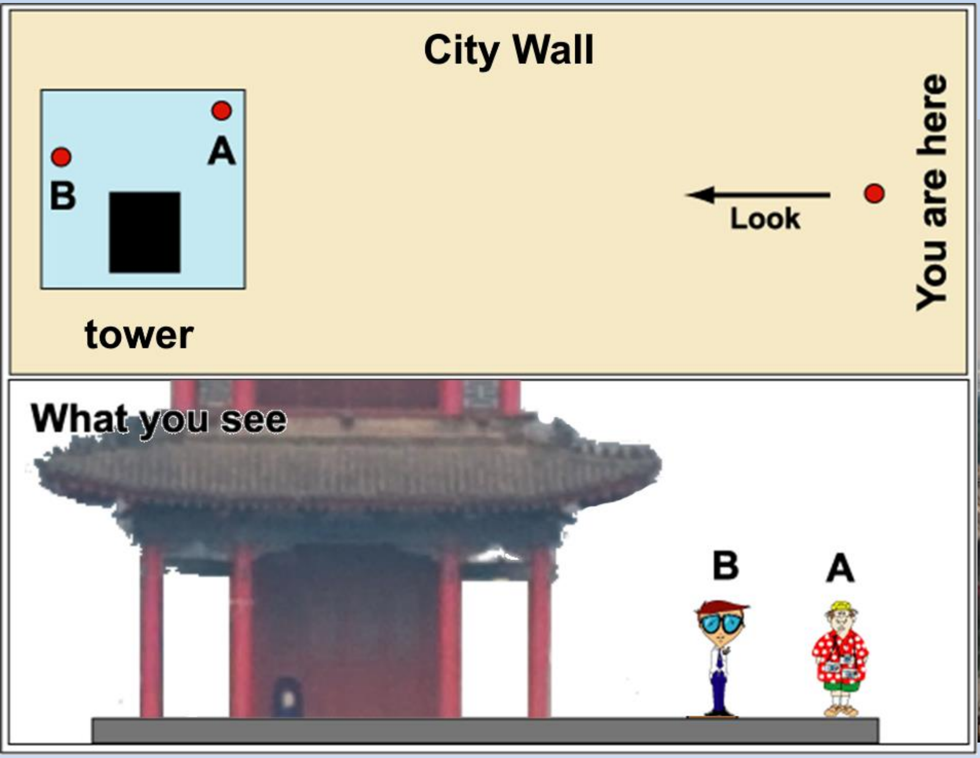
2.6 Seasons and the calendar

2.7 Brightness of celestial bodies

2.8 Planets

2.9 Precession

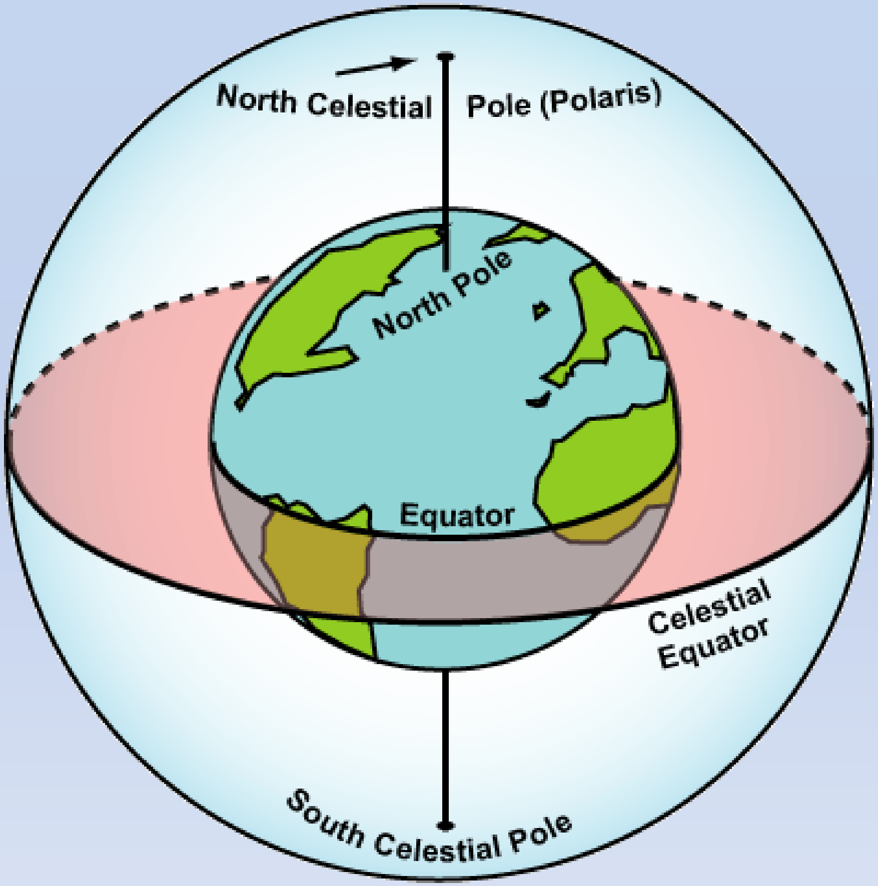
2.1 *Imaginary* Celestial Sphere



Credit: Maros; Wikipedia Commons

- ✓ A and B are standing near to the tower on the City Wall.
- ✓ Even though B is at a larger distance
- ✓ Can't tell by looking at them!

2.1 *Imaginary* Celestial Sphere

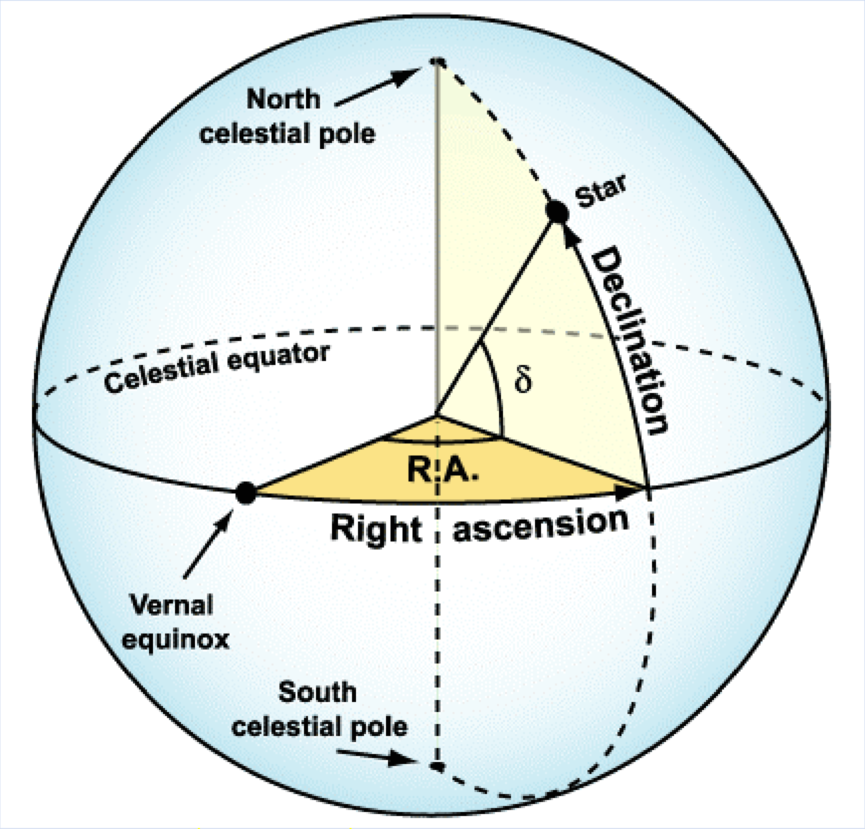


Model of the sky

- ✓ Stars seem to be attached on a sphere – *celestial sphere*
- ✓ We are at the centre
- ✓ Due to the Earth's self rotation, the celestial sphere rotate once a day.
- ✓ Rotation axis through the North Celestial Pole (NCP) and South Celestial Pole (SCP)
- ✓ Polaris close to the NCP

  → almost stationary
- ✓ The celestial equator divides the Northern and Southern hemispheres

2.1 *Imaginary* Celestial Sphere



Equatorial coordinates of a celestial object:

Declination (Dec, δ):

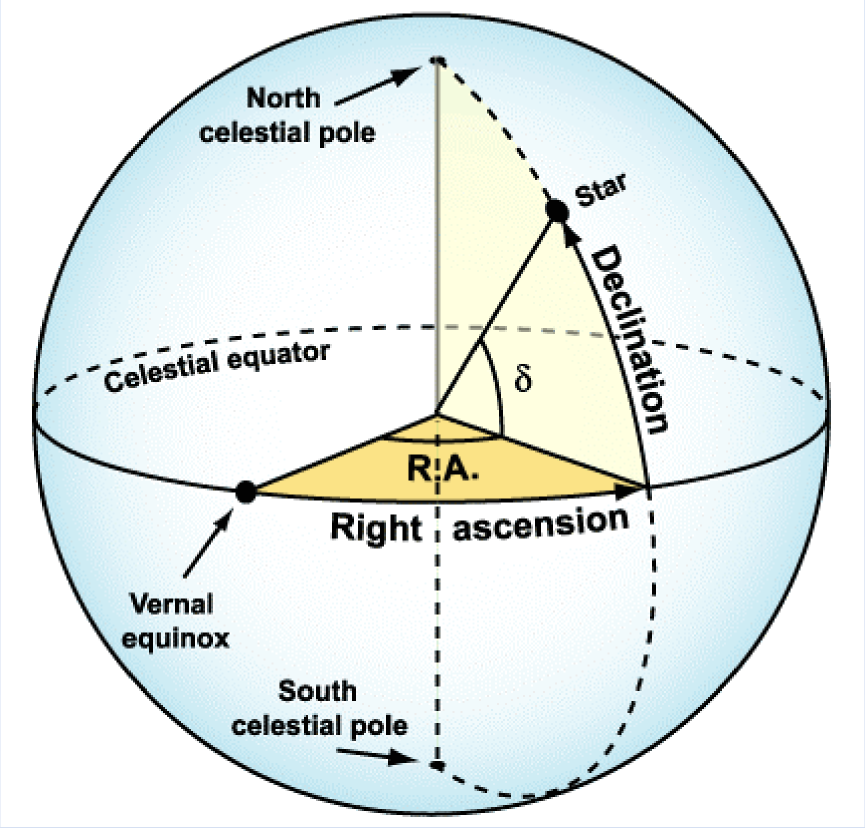
The angle measured northward from the celestial equator.

$-90^{\circ} \le \delta \le 90^{\circ}$

Right Ascension (RA, α):

The angle measured eastward from the Vernal Equinox (春分點), in hr, min, sec (1 hr = 15°)

2.1 *Imaginary* Celestial Sphere

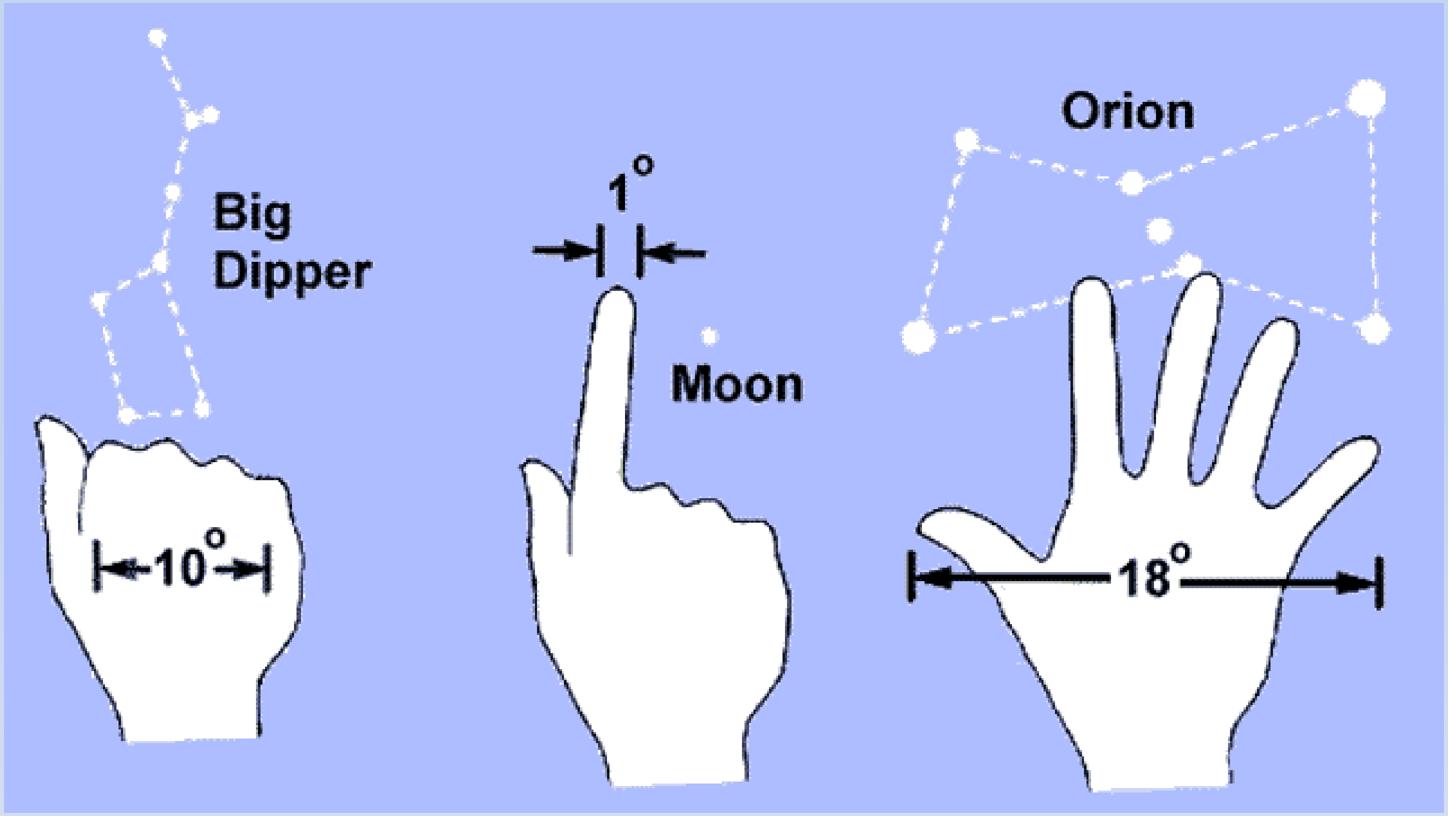


Will Dec and RA of a star change during daily rotation?

- ✓ NO, because DEC and RA are measured relative to a fixed point (vernal equinox) on the celestial sphere

Besides the equatorial coordinate system, there are other systems (see lecture note).

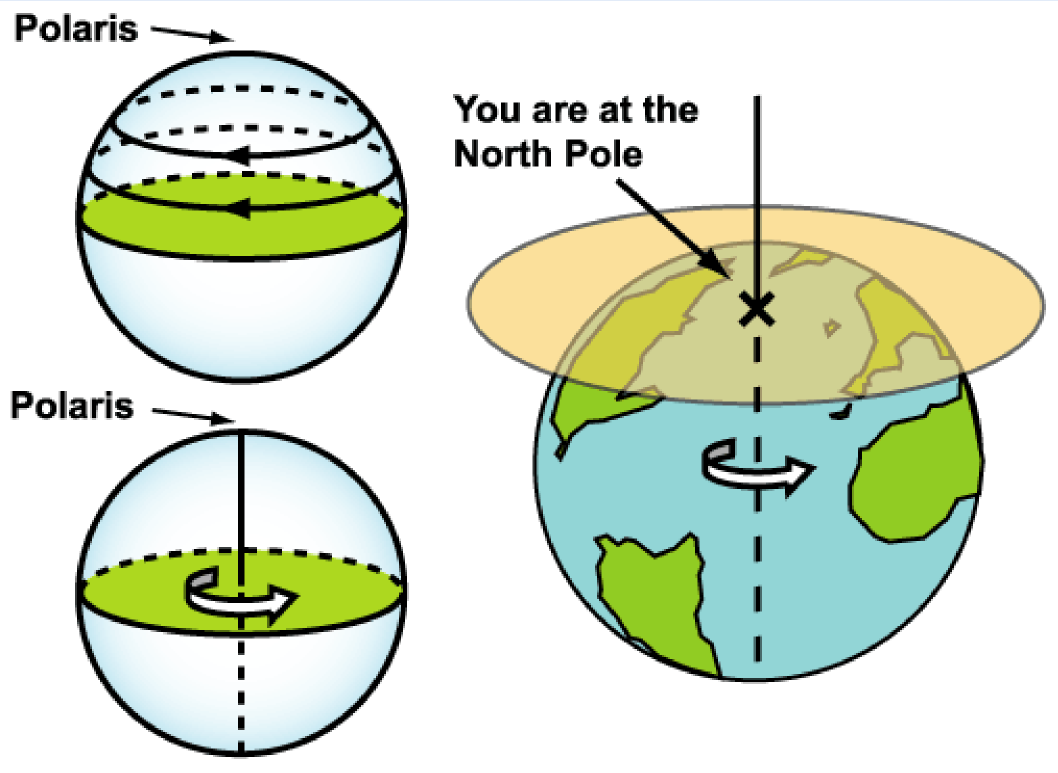
2.1 *Imaginary* Celestial Sphere



Apparent sizes and distances are measured in angles

- ✓ 1 circle = 360° (degrees), 1° = 60′ (minutes), 1′ = 60″ (seconds)

2.2 Daily motion



Note: The zenith is the point directly overhead.

At the North Pole

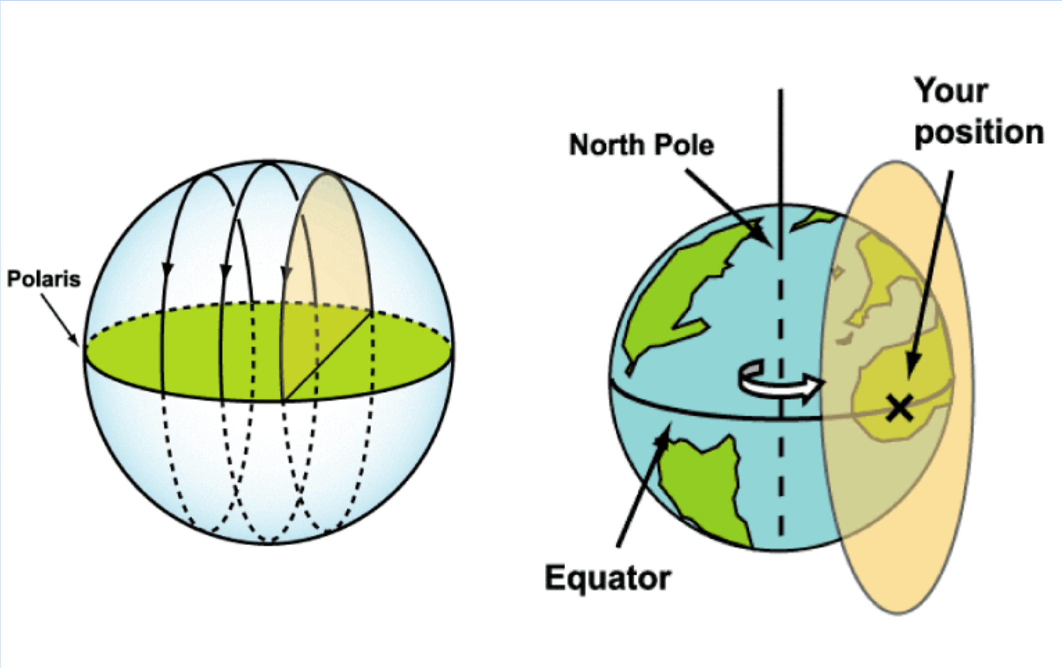
✓Polaris locates directly above you

✓All stars move in counter-clockwise about zenith. Stars move from left to right near horizon.

✓Can see stars in north celestial hemisphere only

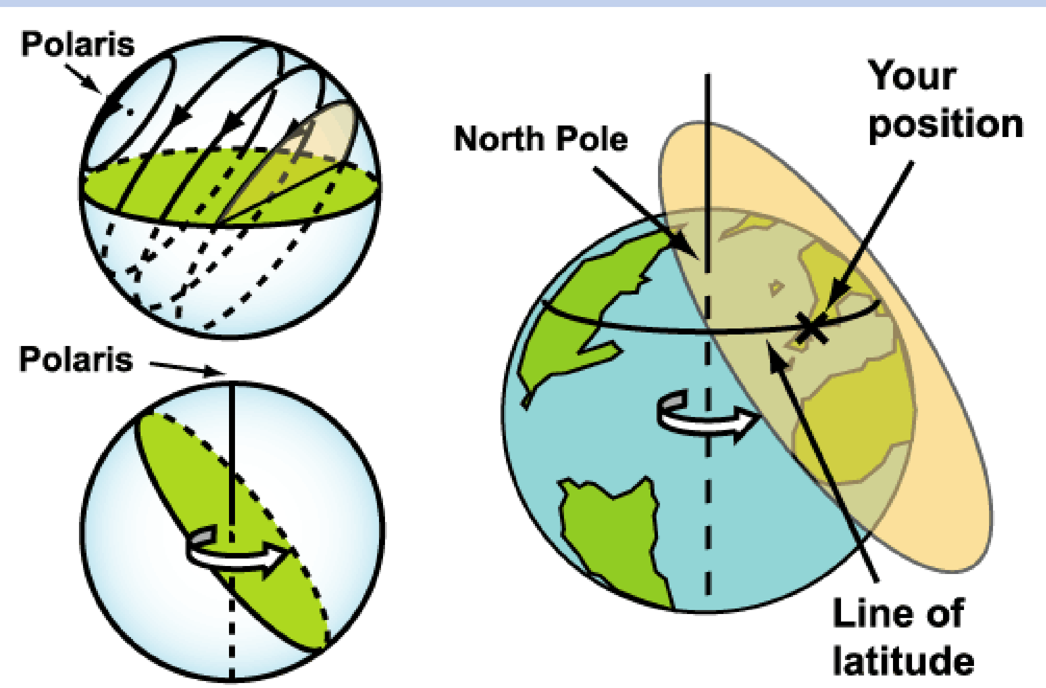
At the South Pole

✓All stars move in clockwise about zenith. Stars move from right to left near horizon.



On the equator

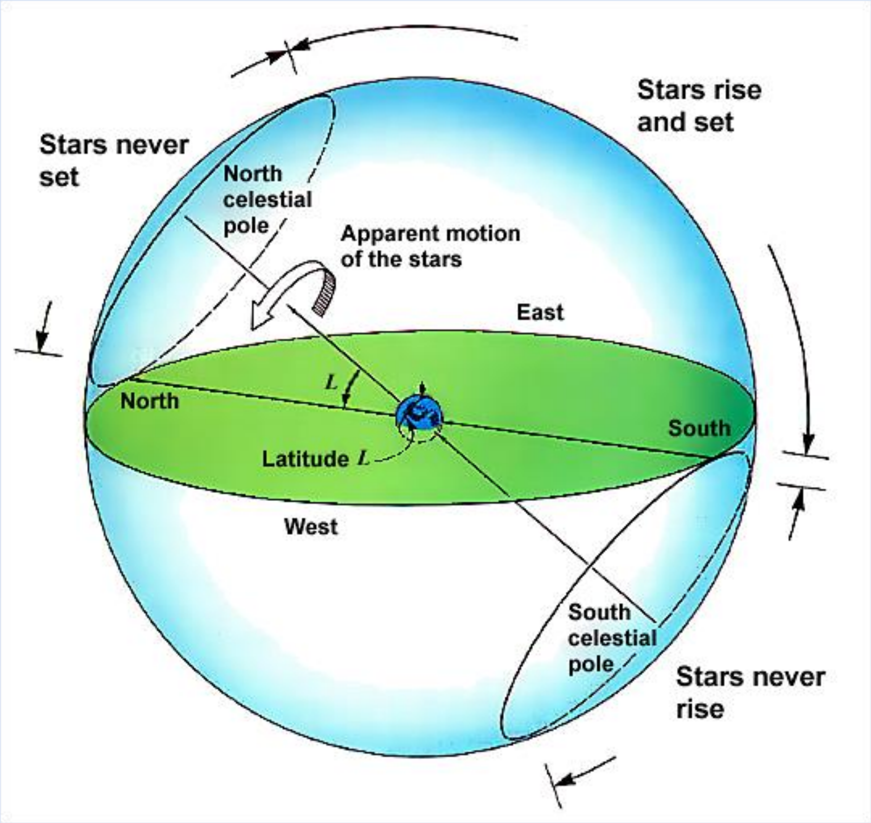
- ✓Polaris locates on the northern horizon
- ✓All stars move along vertical circles
- ✓Can see all stars on the celestial sphere

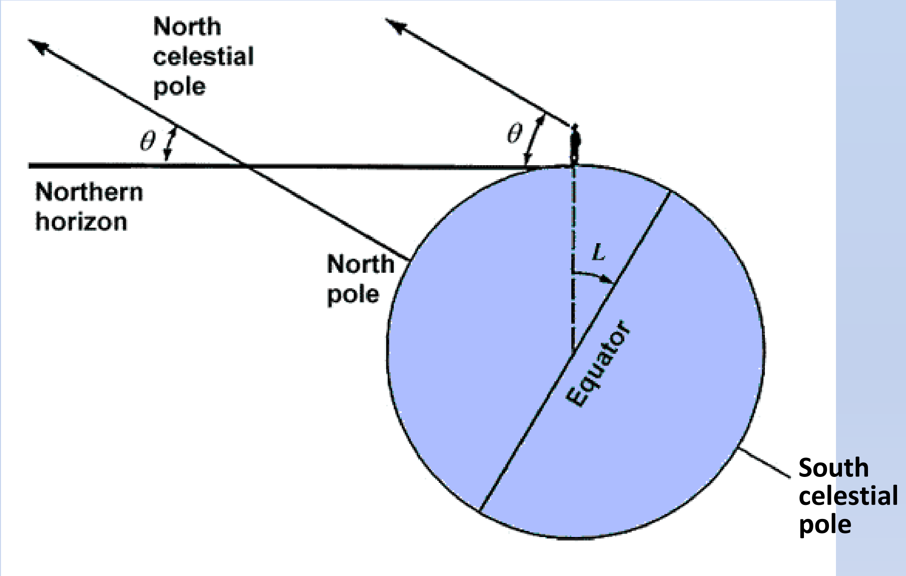


At latitude L

- ✓Polaris locates at an angle above the horizon
- ✓Because of the self-rotation, all stars (including the Sun) rise in the east and set in the west

2.2 Daily motion

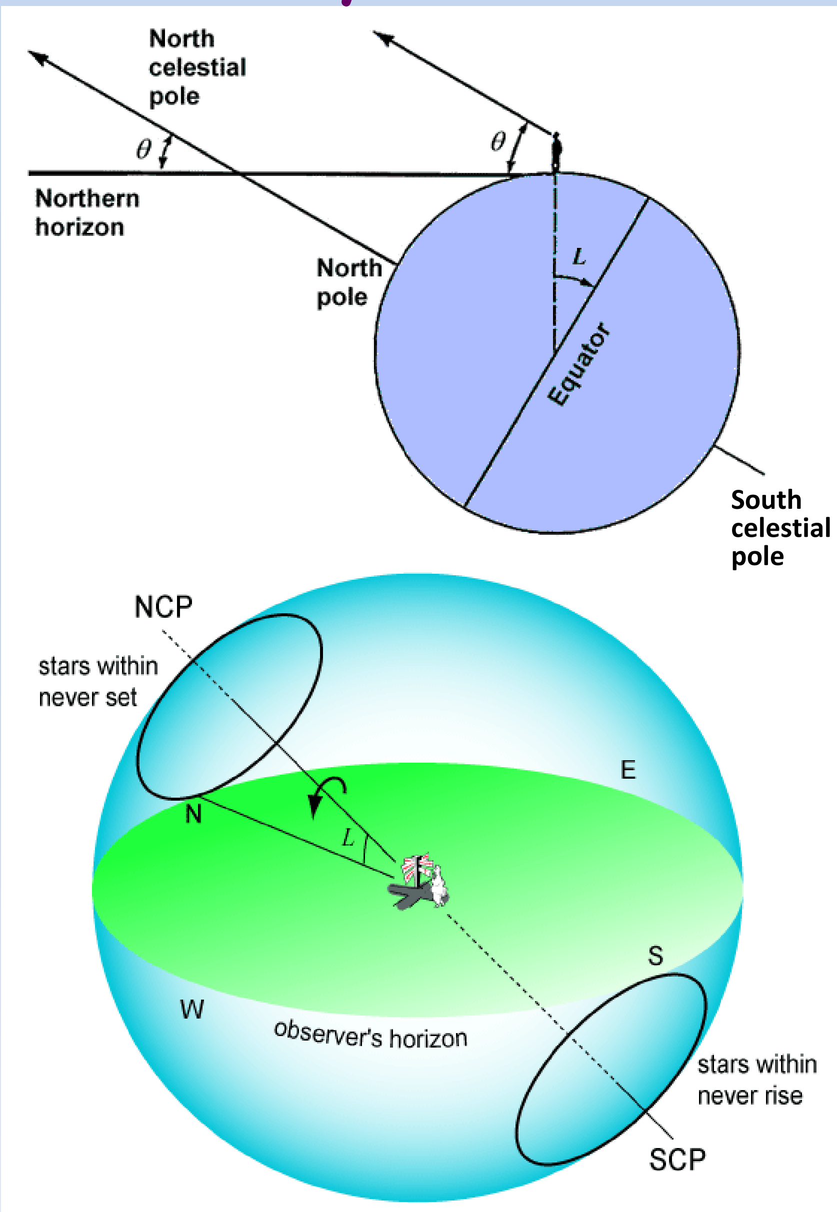




angle of the NCP above the horizon = latitude of the observer

For example, for an observer at 60°N, Polaris is at 60° above the northern horizon. For an observer on the equator, Polaris is right on the northern horizon. For an observer at 60°S, Polaris is at 60° below the northern horizon.

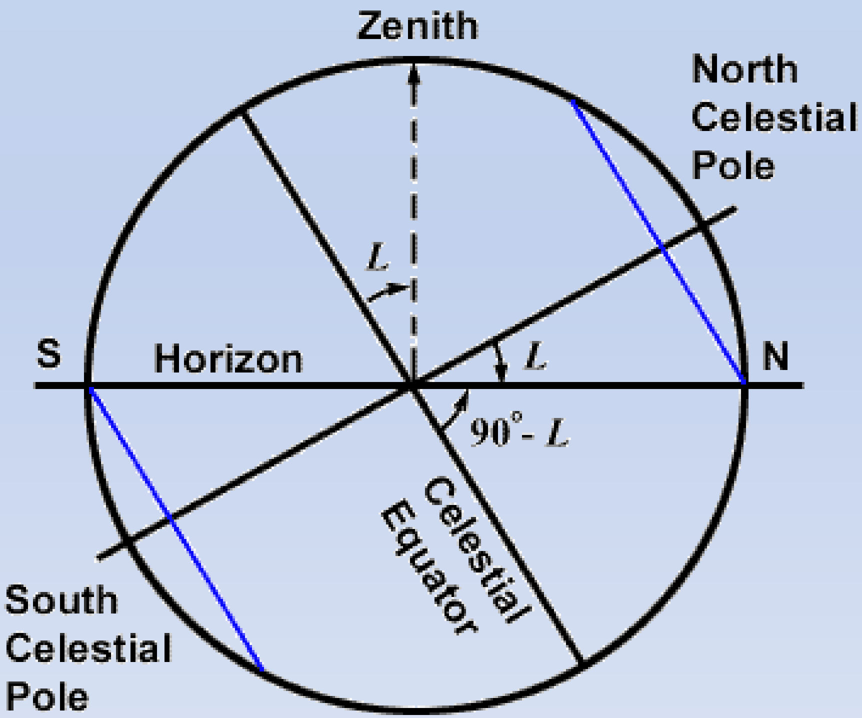
2.2 Daily motion



- ✓ The observer's latitude affects the location of the NCP on the sky.
  → In Xi'an, Polaris is at 34.3° above the northern horizon
- ✓ The constellations we can see also depend on our latitude.
- ✓ Some stars even never set or rise, called *circumpolar star* 拱極星.

2.2 Daily motion

Circumpolar star 拱極星: stars not set or rise.



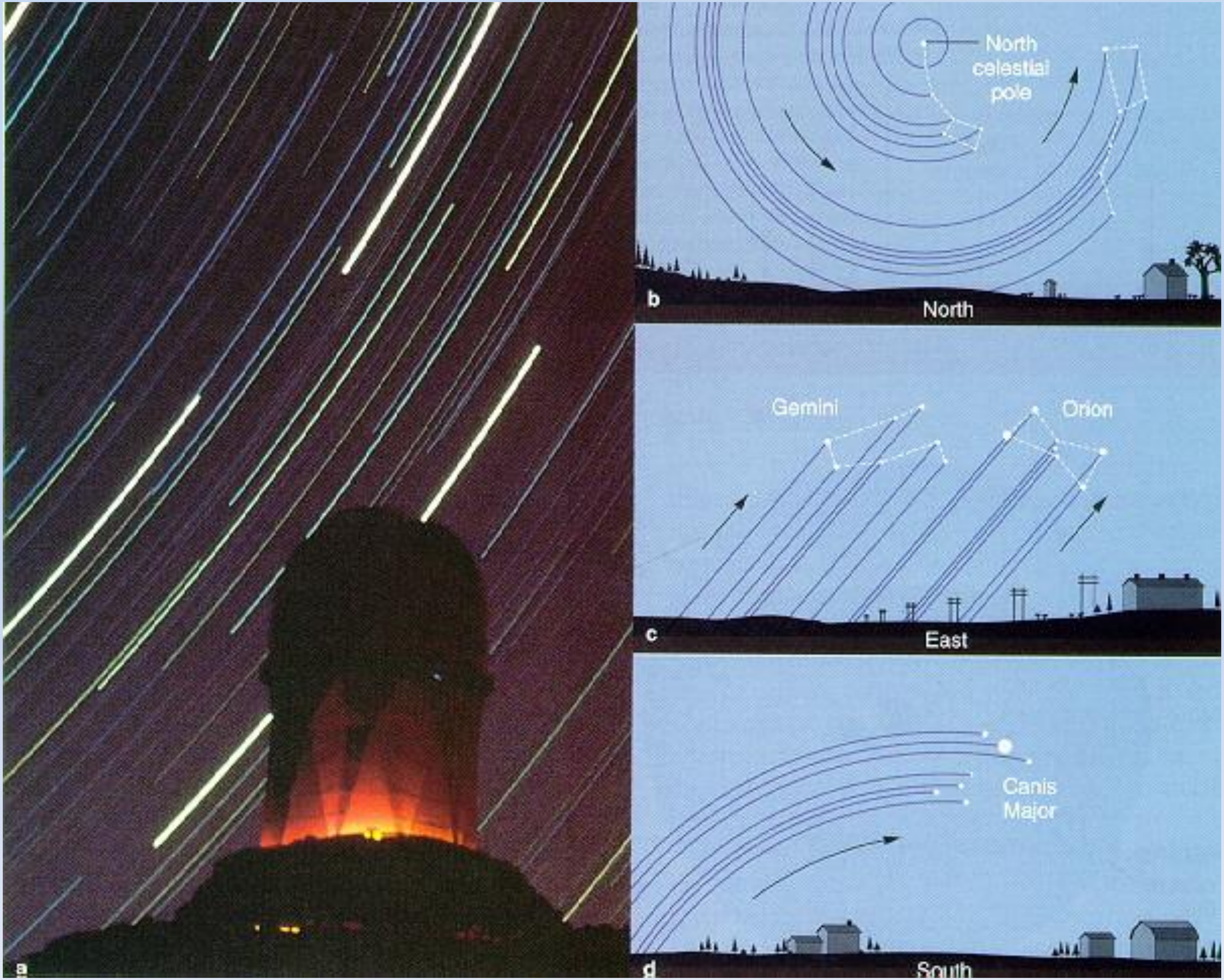
For example, in the northern hemisphere, at a latitude L N,

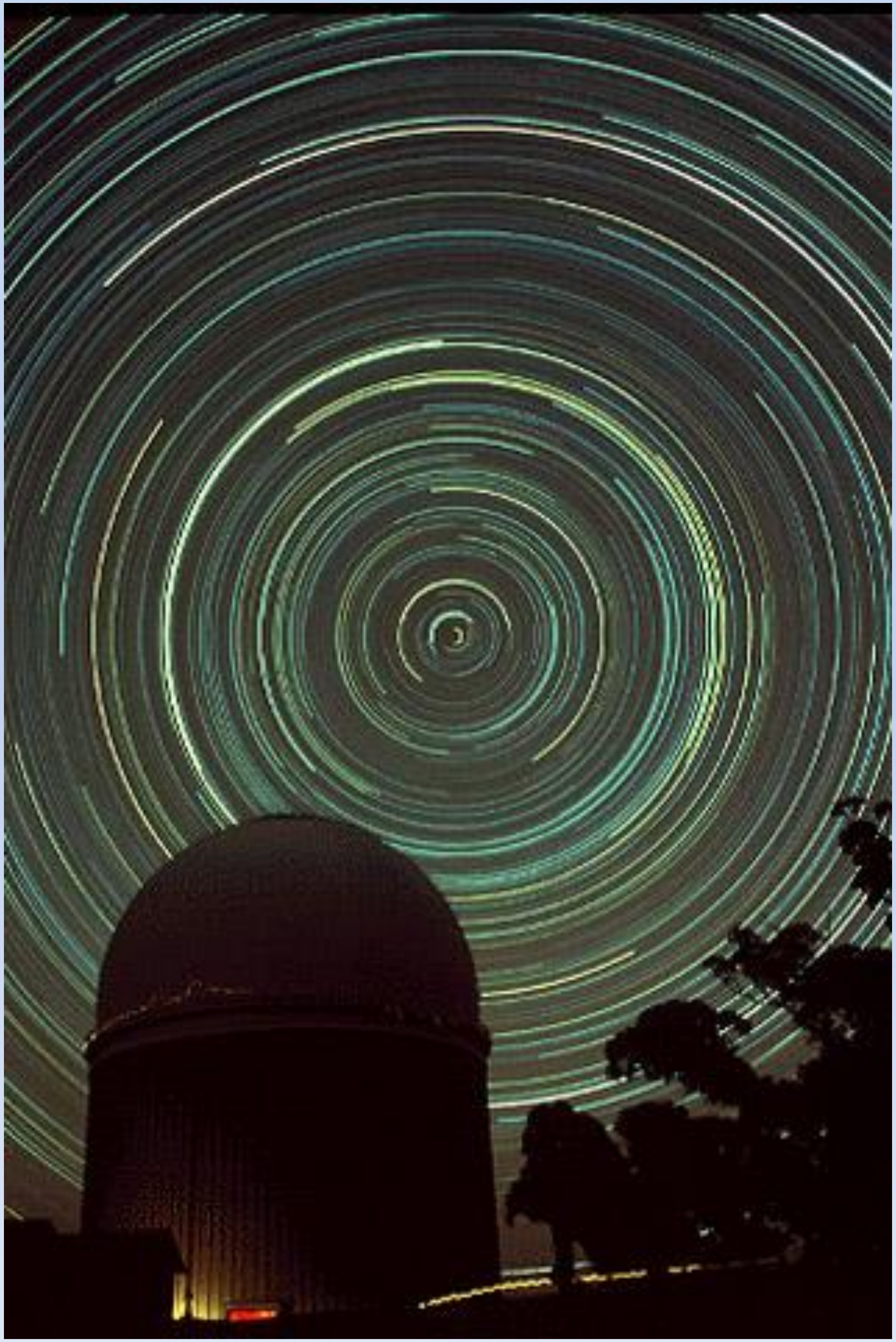
✓stars always above horizon:

$\delta > 90^o - L$

✓stars never above horizon:

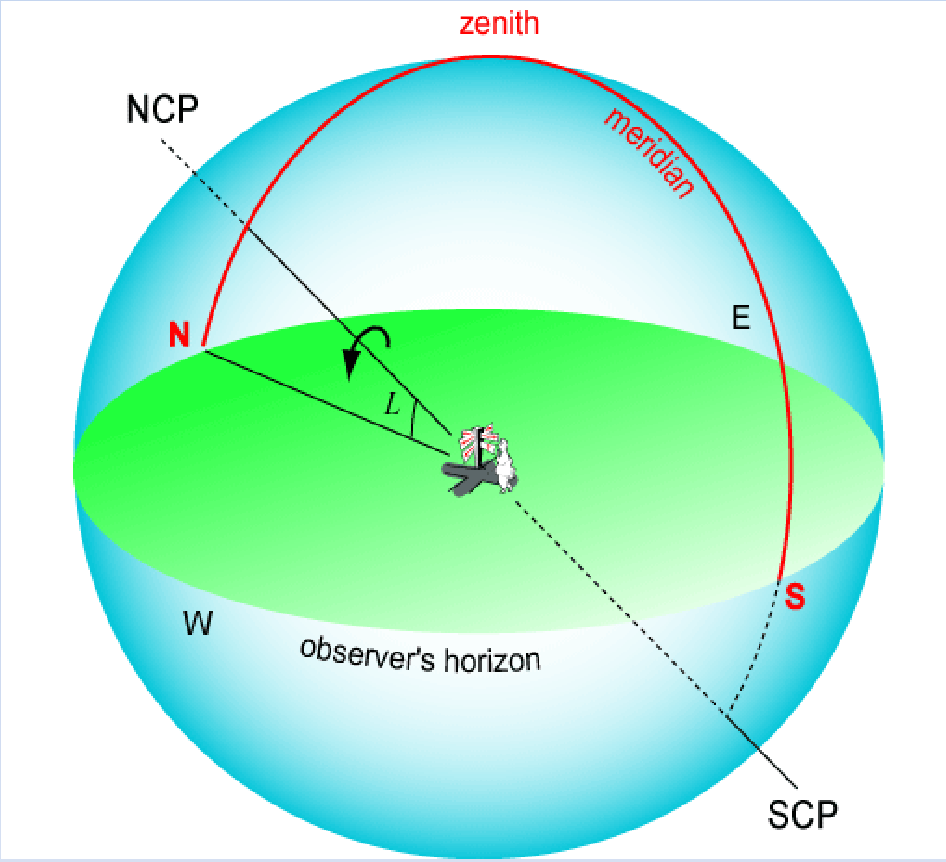
$\delta < -(90^o - L)$


North
celestial
pole
b
North
Gemini
Orion
c
East
Canis
Major
d
South
a



Suppose we are looking at the South, are we in the Northern Hemisphere or the Southern Hemisphere?

2.3 Keeping track of Time



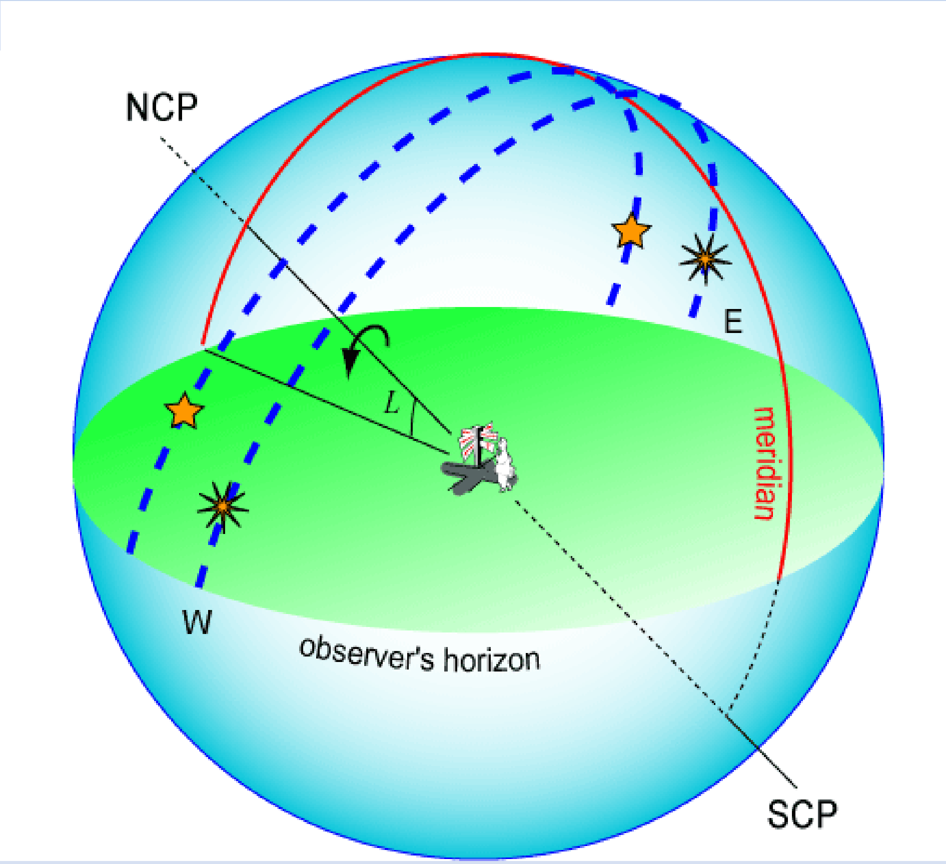
Goal: use the motion of the celestial sphere as a clock.

First, some definitions. Relative to an observer,

✓Zenith (天頂) : point directly overhead

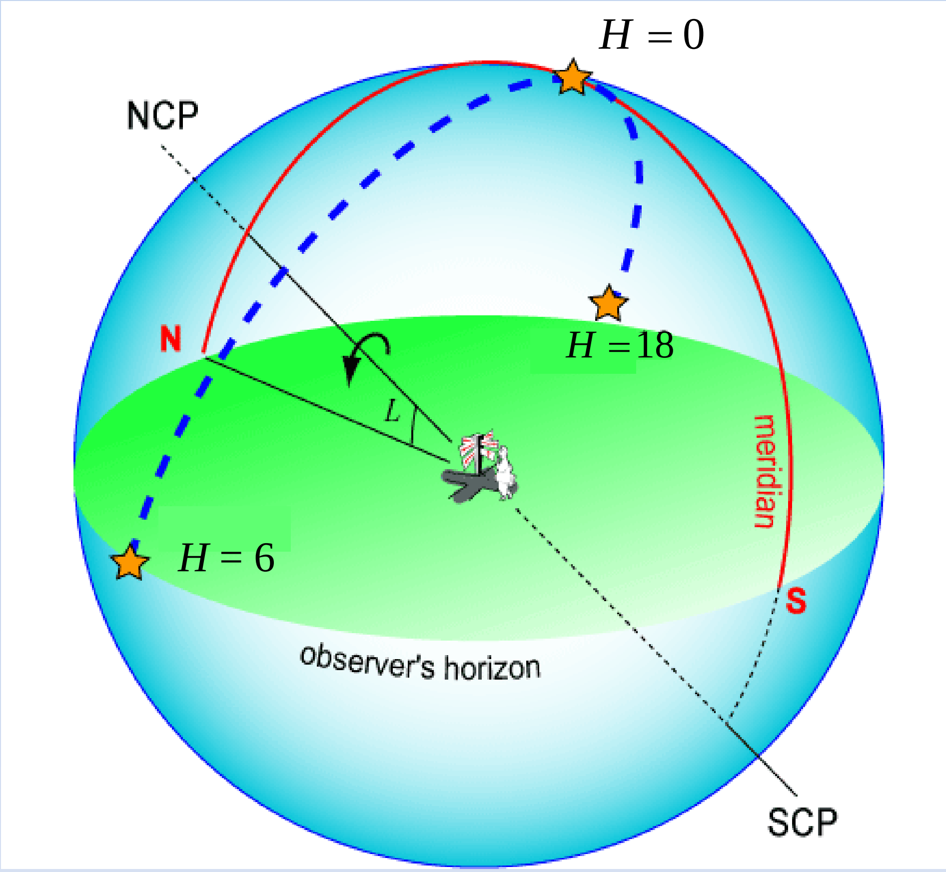
✓Meridian (子午線) : a great circle passing through the zenith, NCP, SCP

2.3 Keeping track of Time



- ✓ Zenith and Meridian are defined relative to the observer, and therefore are *fixed*
- ✓ Stars cross the upper meridian (the NCP-Zenith-SCP line) and the lower meridian once a day

2.3 Keeping track of Time

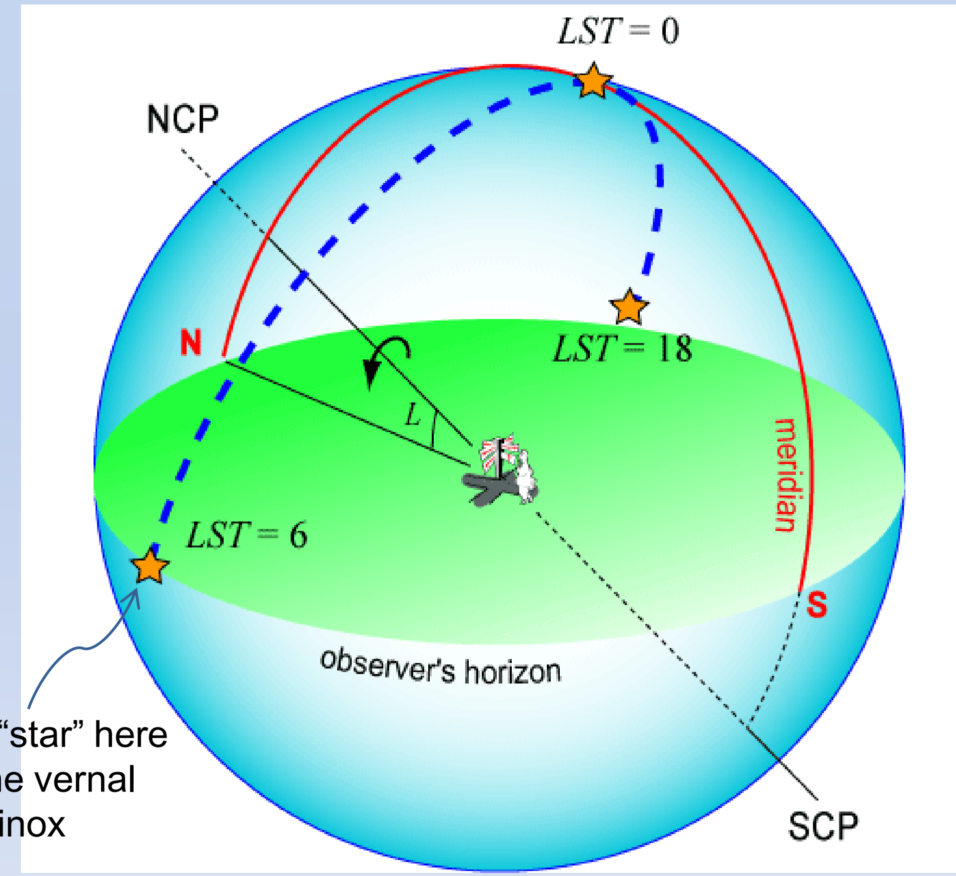


Another definition:

- ✓ Hour angle H of a star is defined as the angle of a star measured from the observer's meridian westward,
- ✓ in hr, min, sec measured from 0 to 24 hr,

  e.g., $H = 0$ when the star is passing the upper meridian

2.3 Keeping track of Time



the “star” here is the vernal equinox

Local sidereal time (地方恆星時, LST)

✓Hour angle of the vernal equinox relative to an observer

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

At the upper meridian

2.3 Keeping track of Time

Sidereal day 恆星日

- ✓ Time between successive passages of the vernal equinox (or any star) across the observer's meridian

- ✓ LST is useful for aiming telescope, but
- ✓ it is not convenient in our daily life!

Traditionally we look for timekeeping system to reflect the position of the Sun.

2.3 Keeping track of Time

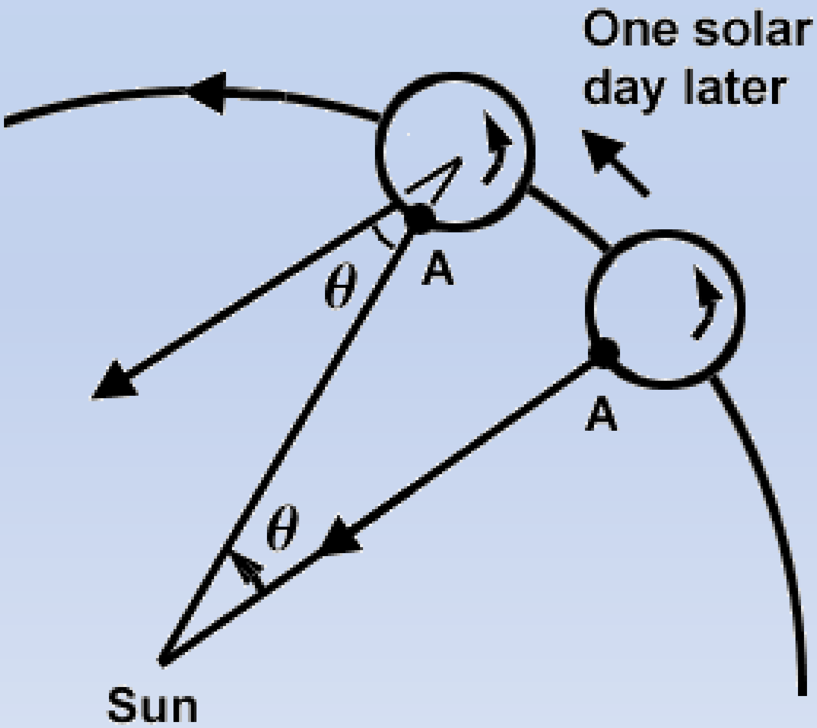
Apparent solar day

✓Time between successive passages of the Sun across the observer's meridian

✓Noon and midnight are defined as the Sun across upper and lower meridian

But Sun is <u>not</u> a good timekeeper!

2.3 Keeping track of Time



- ✓ Due to the Earth's orbital motion, one apparent solar day is slightly longer than one sidereal day
- ✓ The Earth's orbit is elliptical (Kepler's 1st law), and its orbital speed changes (Kepler's 2nd law), so the length of an apparent solar day varies over the year

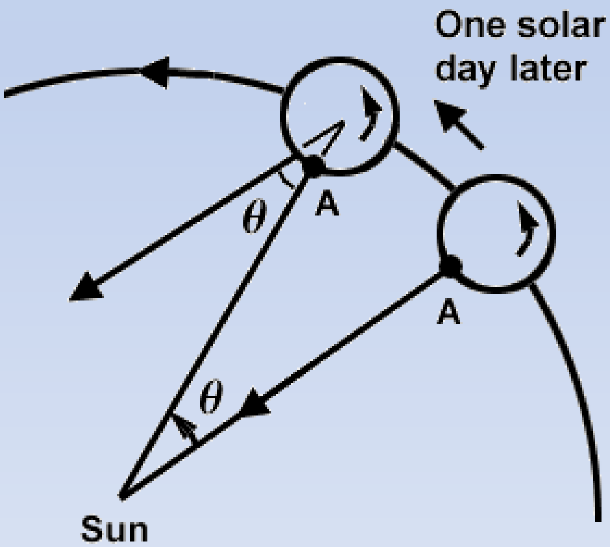
2.3 Keeping track of Time

- ✓ **Mean sun**: imaginary object moves uniformly in a perfect circle
- ✓ **Mean solar day**: The time between successive passages of the *mean sun* across the observer's meridian.
- ✓ It is exactly 24 hours a day. Our clock measures mean solar day.

2.3 Keeping track of Time

Question: Given that there are 365.2422 *mean solar days* in one year.

1 mean solar day = S sidereal day, S = ?



Angular speed of self-rotation,

$\omega = 360^o$ (sidereal day)$^{-1}$

Angular speed of orbital motion Ω ,

$\Omega = 360^o /365.2422$ (mean solar day)$^{-1}$

$= 360^o /(365.2422\, S)$ (sidereal day)$^{-1}$

So, $\omega S = 360^o + \Omega S$

$S = 1 + 1/ 365.2422$

$\approx 1 + 2.7379 \times 10^{-3}$

1 sidereal day = 23 hr 56 min 4.1 sec of mean solar time

2.3 Keeping track of Time

✓Universal Time (UT): Mean solar time at Greenwich 格林威治

✓Time zones: each defined by longitude of each 15° (i.e., 1hr). The same *Standard time* in each zone. that is what we now use

✓Standard time (ST): mean solar time for a meridian at the center of the zone (assuming that they are evenly spaced). e.g., longitude of Hong Kong is 108.9°, keep ST at meridian at 120° E

China Standard Time = UT + 8 hr

2.3 Keeping track of Time

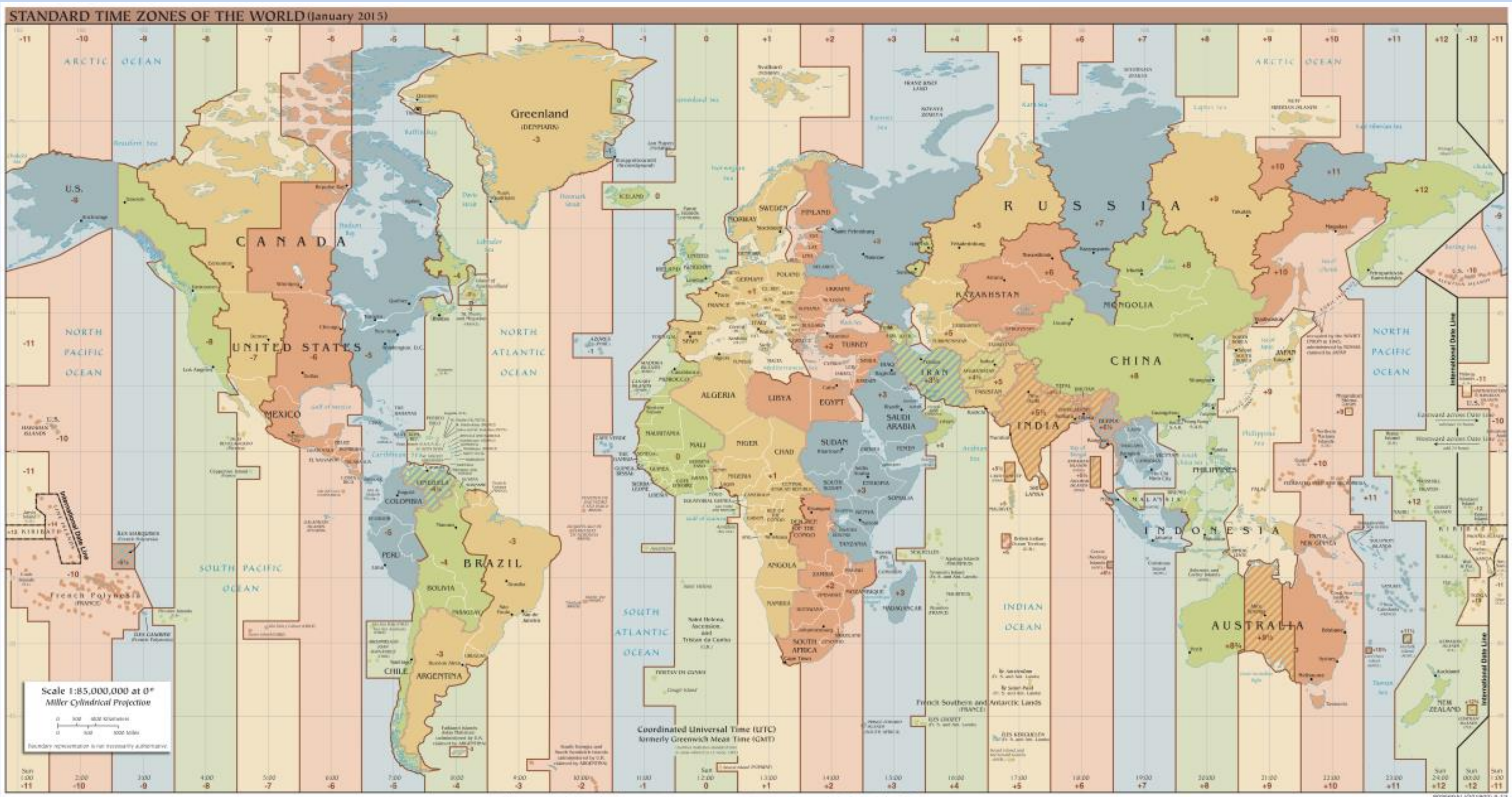
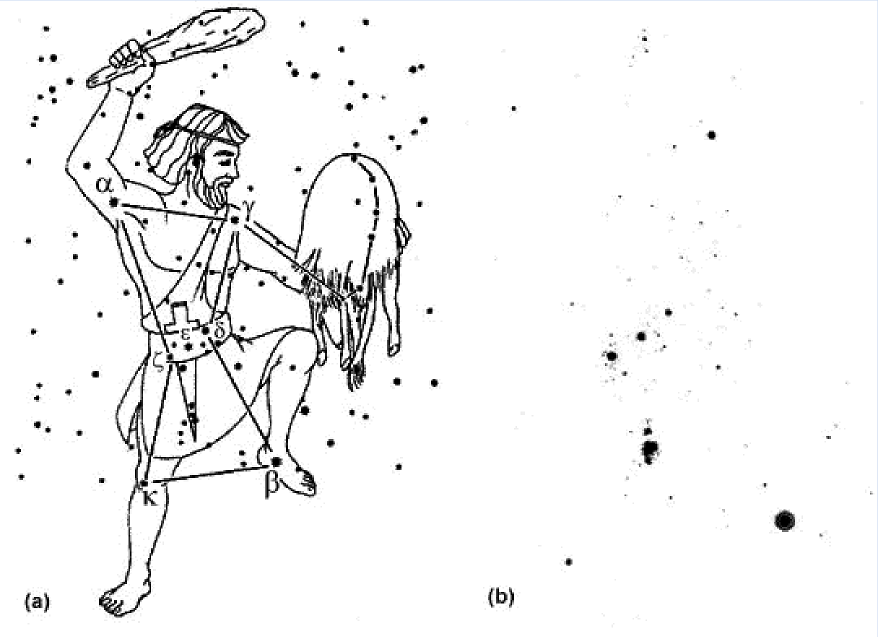


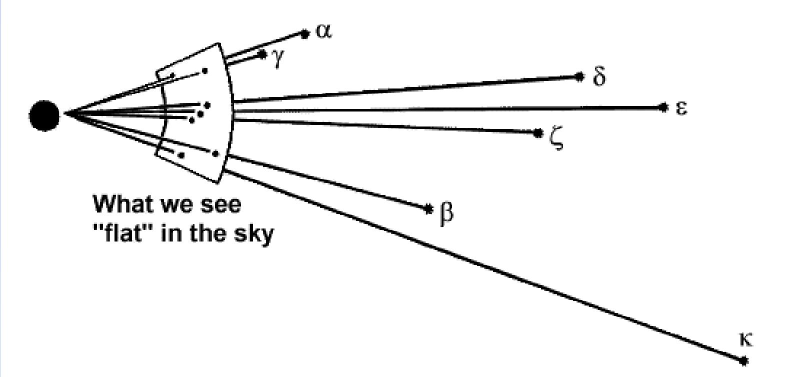
Image credit: Wikipedia Commons

Greenwich, UK

International date line

2.4 Constellations





- ✓ Constellations: *Visual groupings* of stars
- ✓ Totally 88 today, some added in modern days, e.g., Telescopium 望遠鏡座.
- ✓ Names of stars in a constellation: brightest star α, then β etc.,

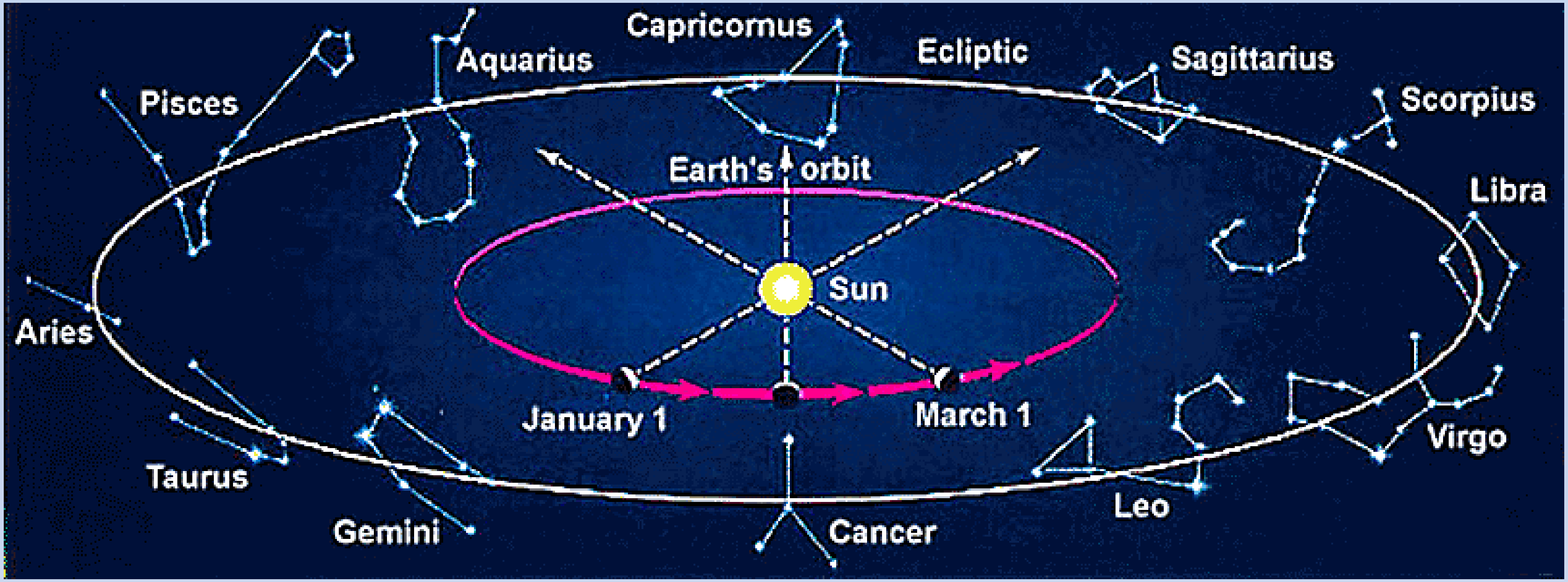
  e.g. Sirius 天狼星 known as α Canis Major 大犬座α
- ✓ Usually no correlation among the stars in the same constellations

獵戶座 Orion

M42

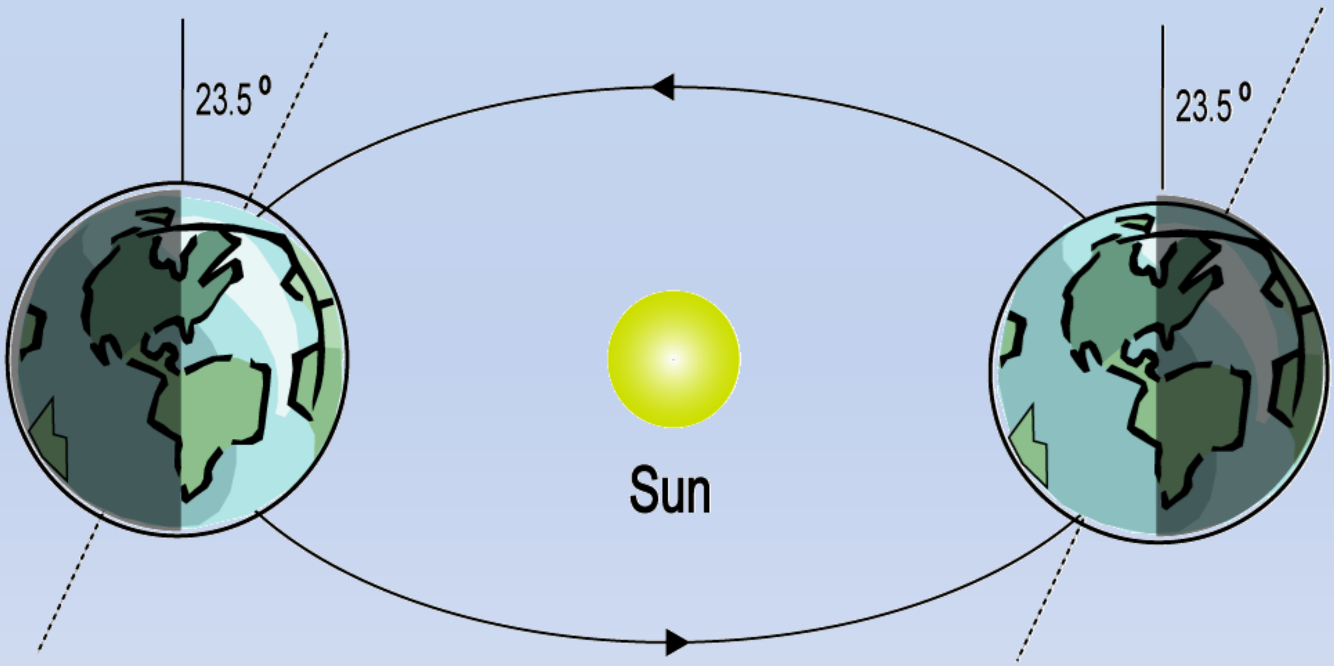
天蠍座 Scorpius

2.5 Apparent motions of the Sun



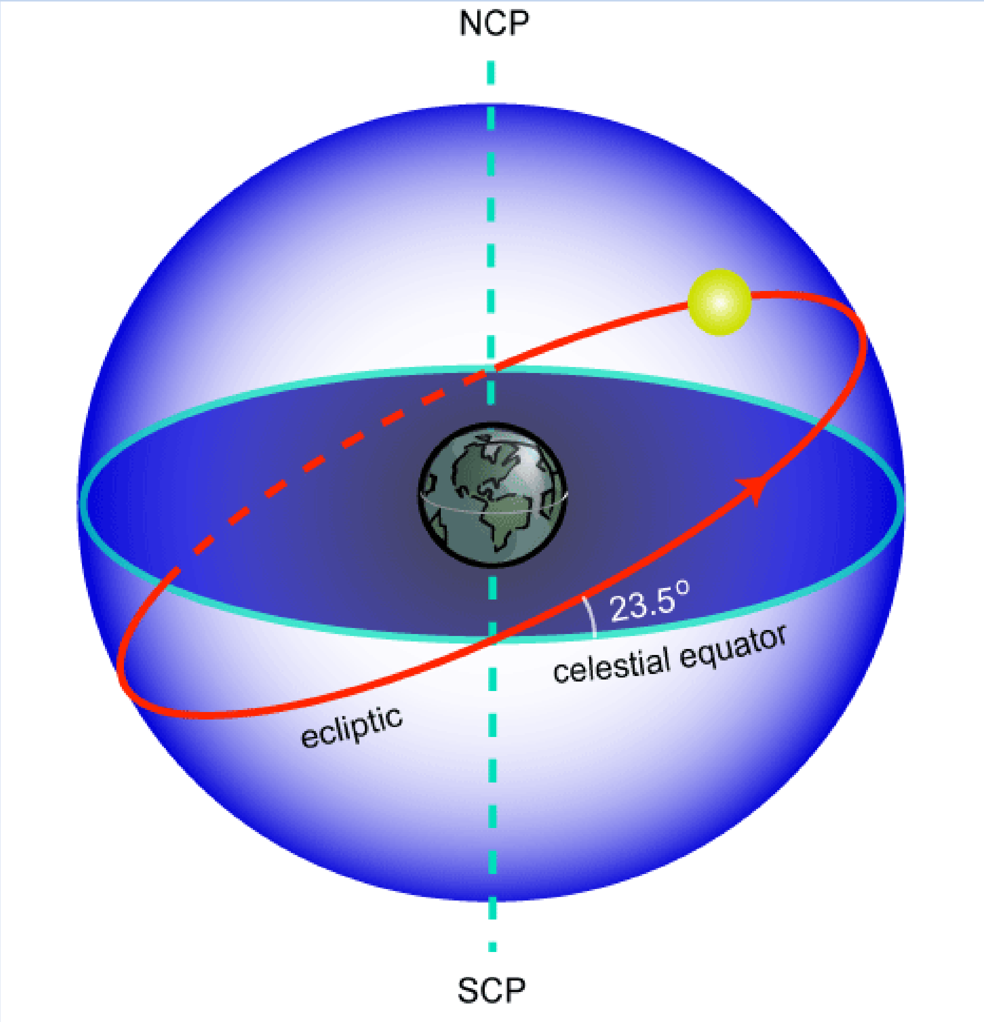
- ✓ Daily motion: self-rotation of the Earth → the Sun and all celestial bodies move across the sky once every day.
- ✓ Yearly motion: orbital motion of the Earth
- ✓ The Ecliptic 黃道: apparent motion of Sun in a year
  - ➢ across 13 constellations (12 + Ophiuchus 蛇夫座)
  - ➢ the Sun drifts by ~1° per day on the celestial sphere

2.6 Seasons and the calendar

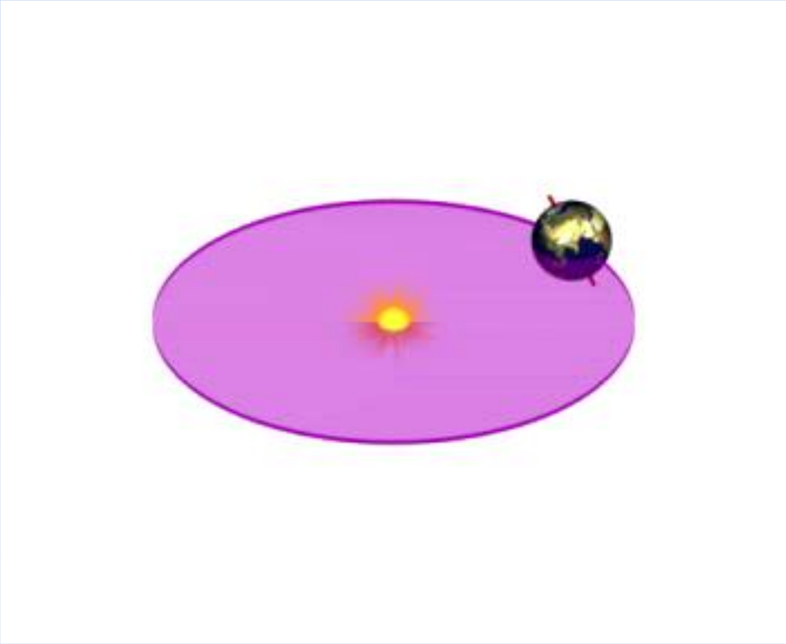


- ✓ The Earth' axis is 23.5° from the perpendicular direction
- ✓ The Earth's equator (and the celestial equator) is 23.5° from its orbital plane (and thus the ecliptic)

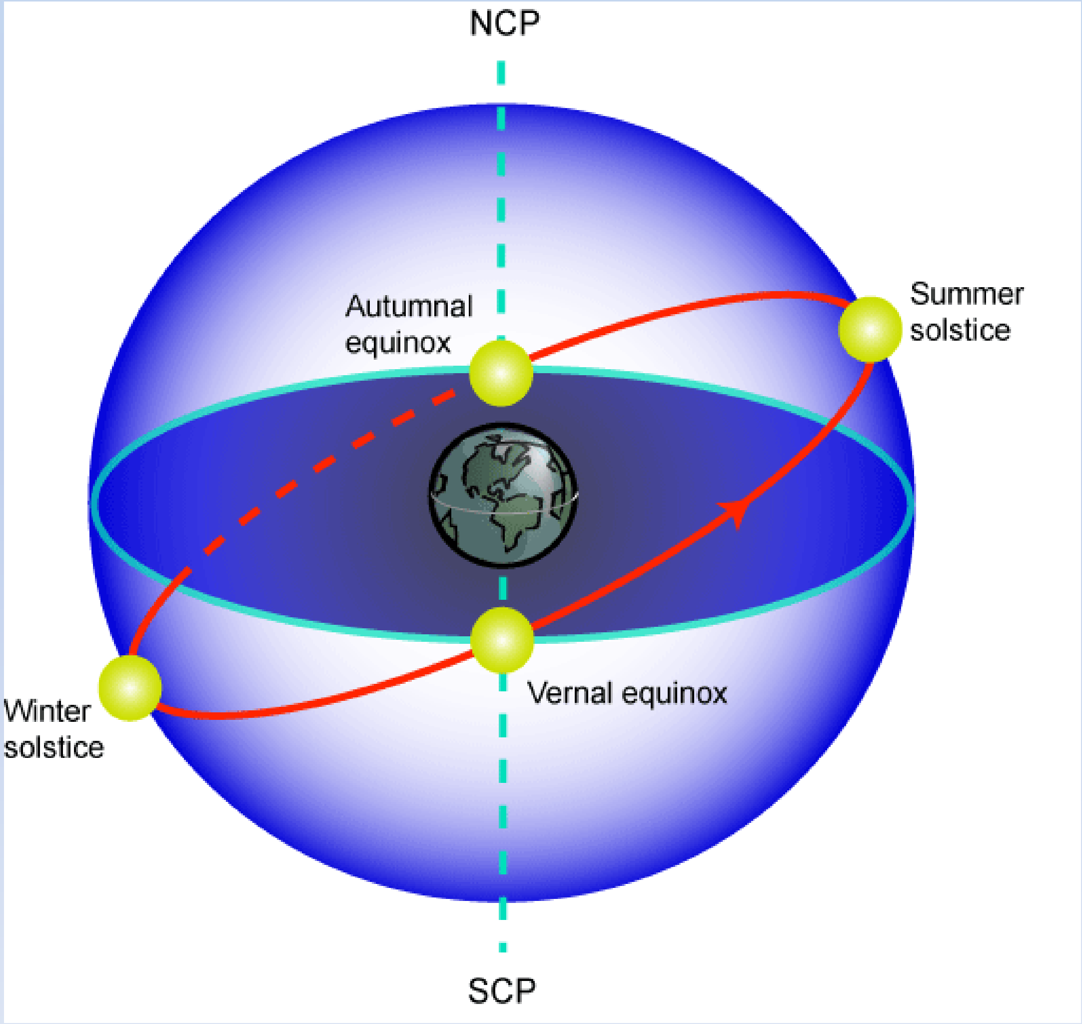
2.6 Seasons and the calendar



✓The ecliptic makes an angle of 23.5° with the celestial equator



2.6 Seasons and the calendar



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

✓**Summer solstice** (夏至) 22/6: The Sun is farthest North, and makes an angle of 23.5° northwards

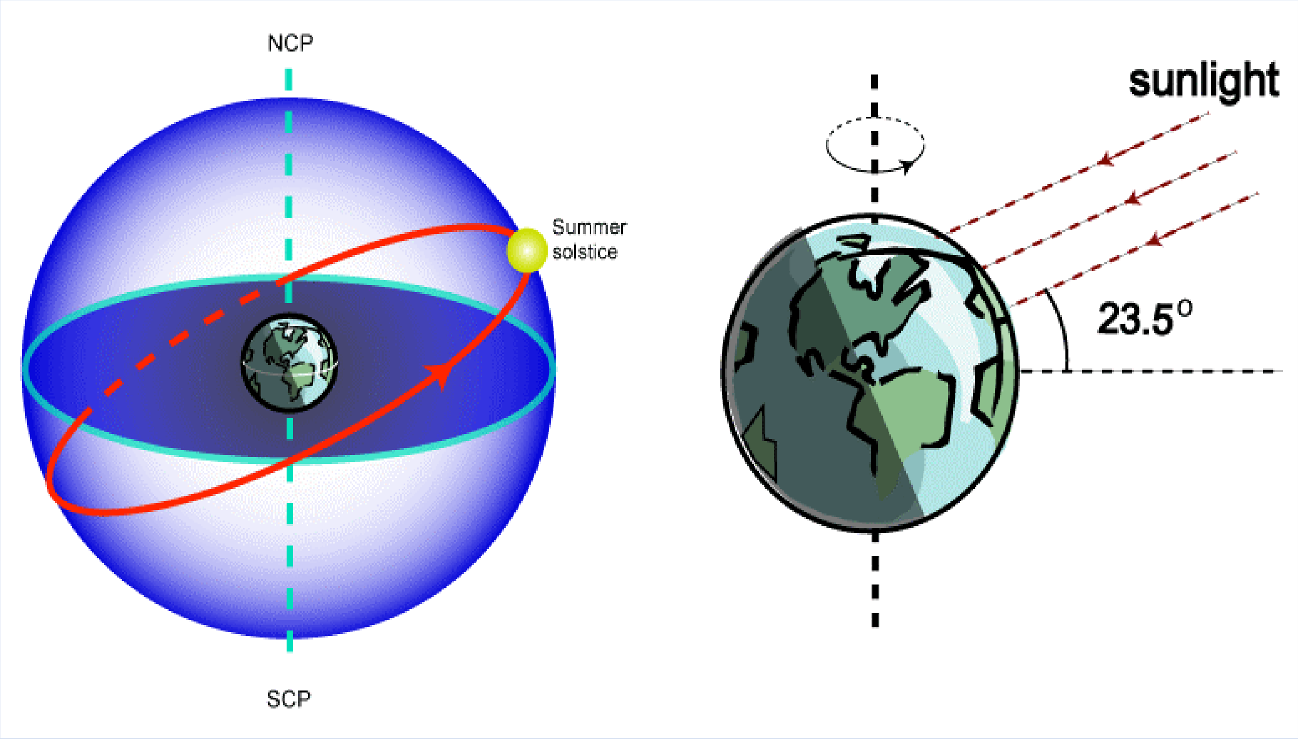
✓**Autumnal equinox** (秋分) 23/9: The Sun crosses the celestial equator moving southward

✓**Winter solstice** (冬至) 22/12: The Sun is farthest South, and makes an angle of 23.5° southwards

2.6 Seasons and the calendar

Q: Why is it longer daytime in summer?

the Sun at **Summer solstice** (夏至)



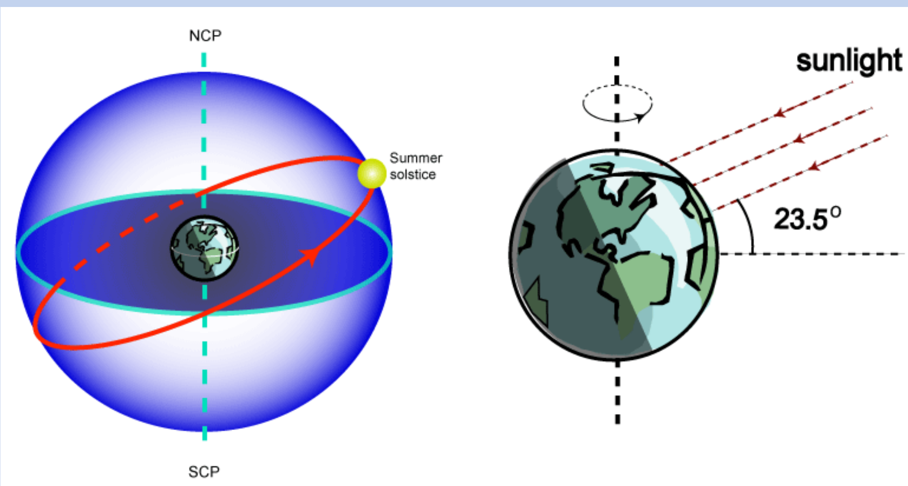
✓Sunlight from north of the equatorial plane at 23.5°

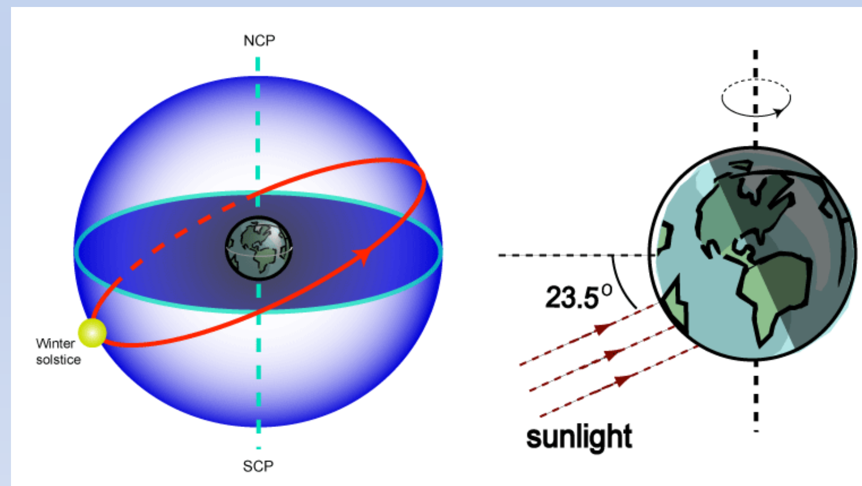
Longest daytime in the Northern hemisphere;

Shortest daytime in the Southern hemisphere

2.6 Seasons and the calendar

Q: How long of the daytime at equator when the Sun travels to summer or winter solstice, vernal or autumnal equinox?





No matter where the Sun is, there are 12 hrs of daytime and 12 hrs of night time at the equator

2.6 Seasons and the calendar

Q: Why is it so hot in summer?

Is it because the Earth is closer to the Sun in summer?

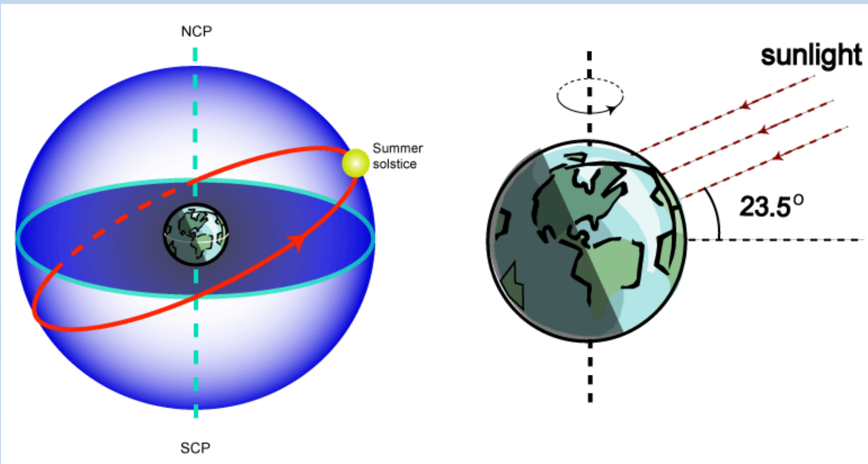
But the Earth is closest to the Sun (perihelion) around January 2; farthest away from the Sun aphelion) around July 2.

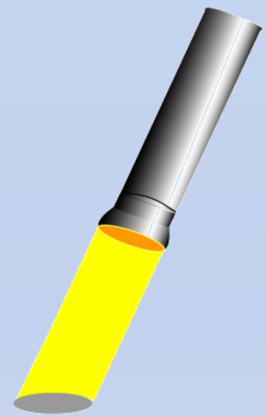
So why is it hotter in summer?

2.6 Seasons and the calendar

Q: Why is it so hot in summer?

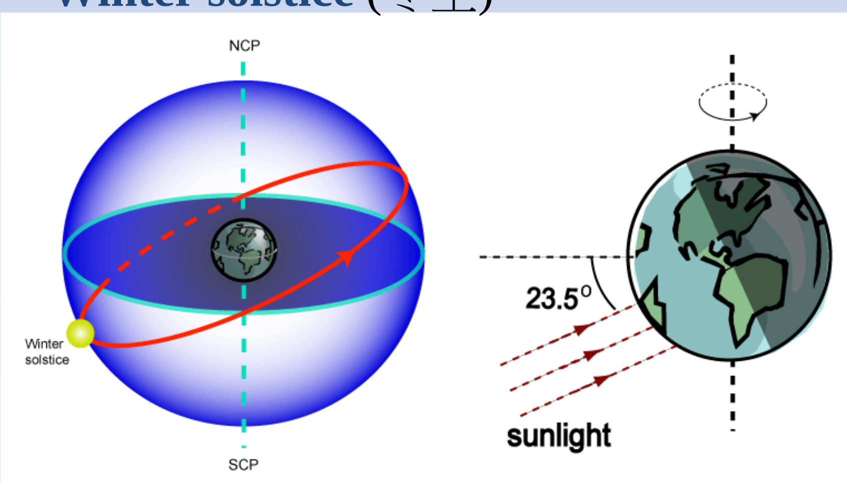
Summer solstice (夏至)

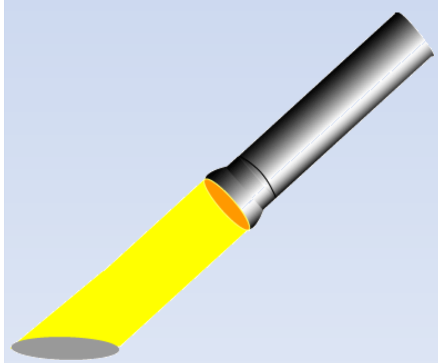




✓Sunlight does not spread much, hence hot in June in Northern hemisphere.

Winter solstice (冬至)

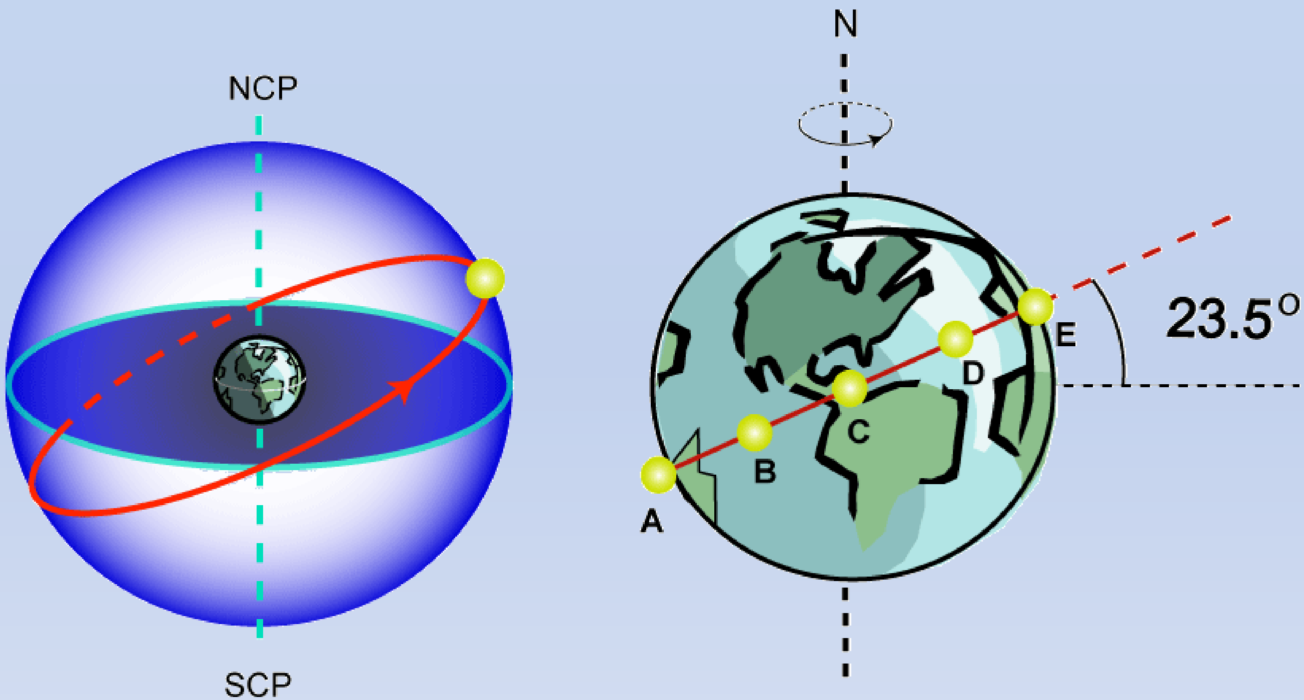




✓Sunlight strikes the ground at a lower angle in the Northern hemisphere. Sunlight spread more. Less power per unit area, and thus colder in December.

2.6 Seasons and the calendar

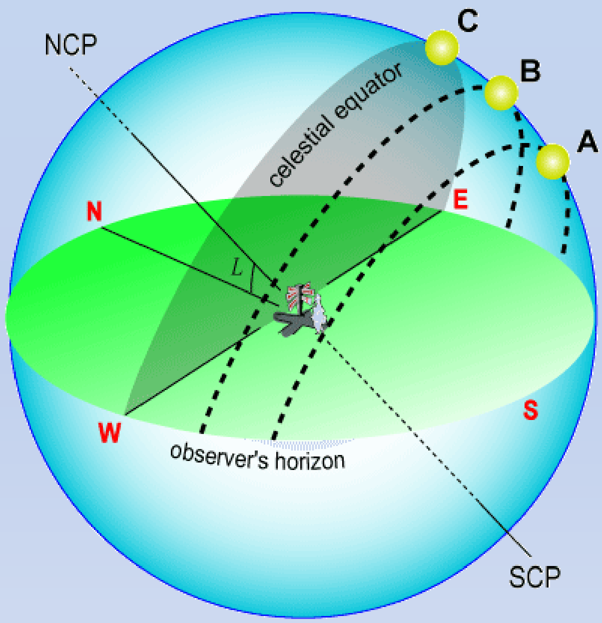
Q: Where does the Sun rise and set?

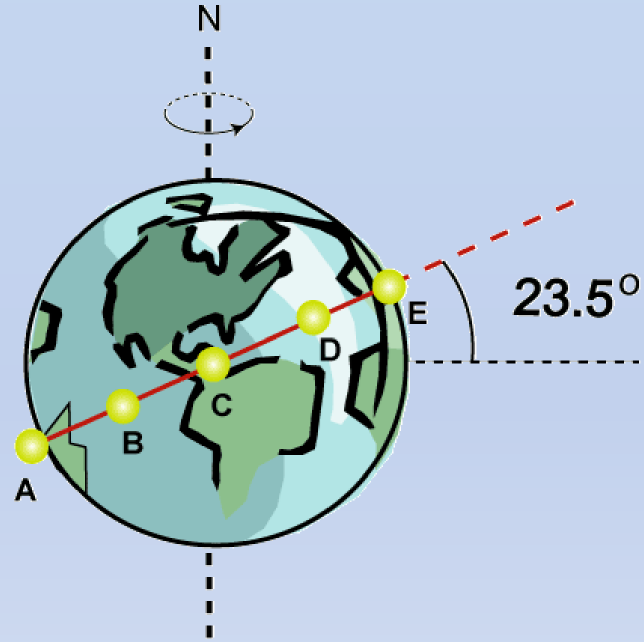


- ✓ The Sun appear at positions A to E when the Sun is moving from *winter solstice* (A) to *vernal equinox* (C) to *summer solstice* (E).

2.6 Seasons and the calendar

Q: Where does the Sun rise and set?

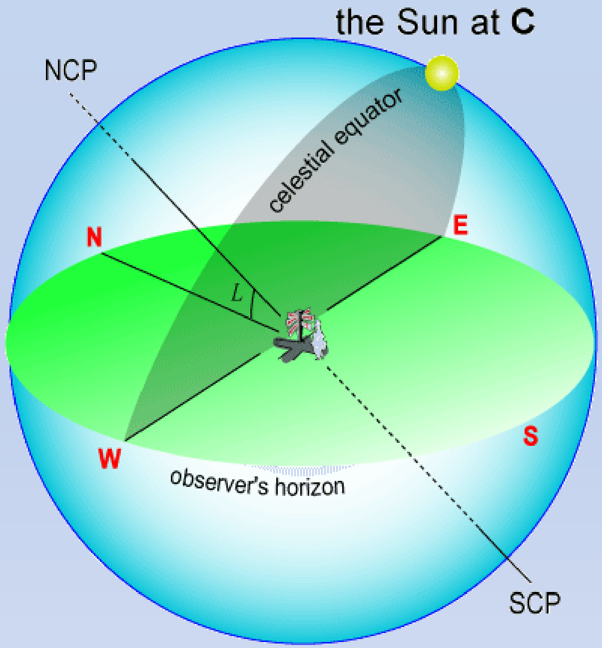


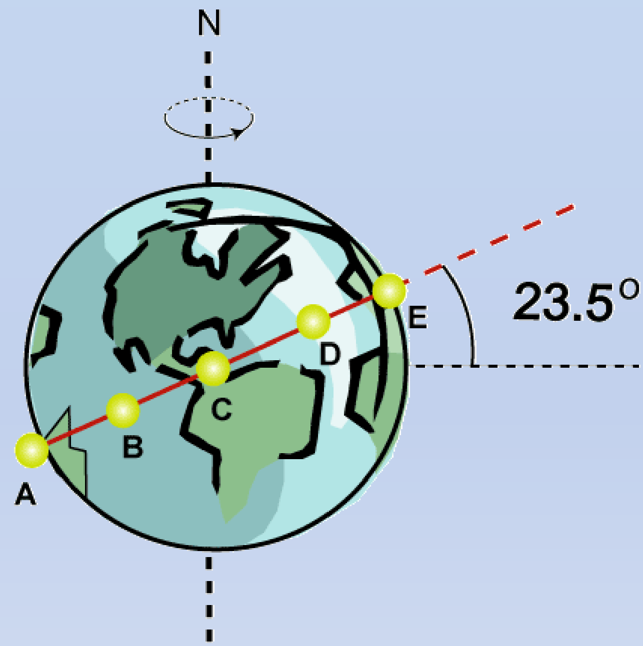


- ✓ Recall that the daily motion comes from the Earth's self-rotation.
- ✓ The Sun at A (*winter solstice*) to C (*vernal equinox*): the Sun appears to move parallel to the celestial equator, but shifting northward.

2.6 Seasons and the calendar

Q: Where does the Sun rise and set?

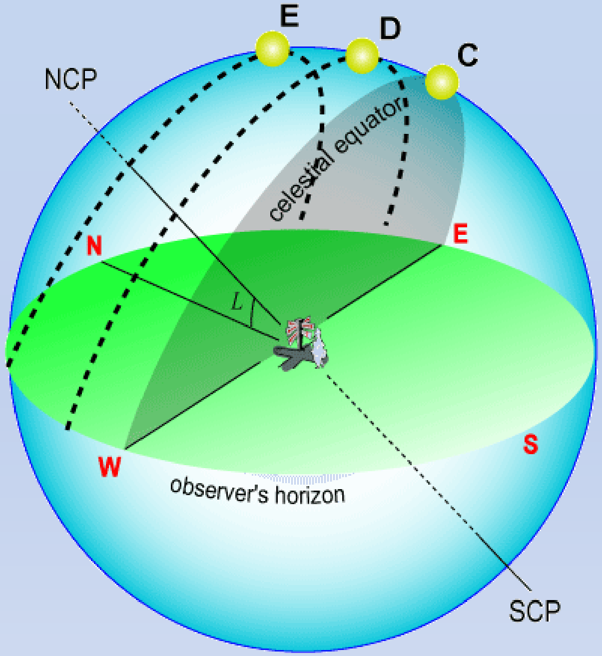


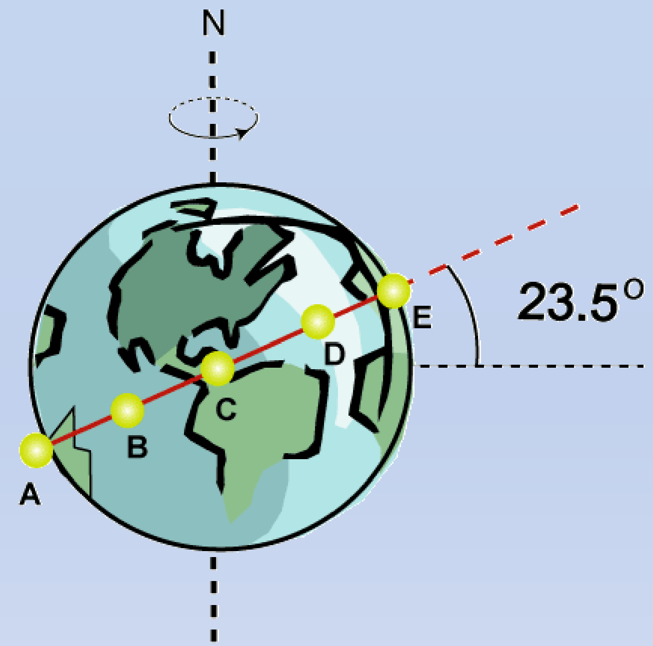


- ✓ On vernal equinox or autumnal equinox (the dates), the Sun move along the celestial equator.
- ✓ The Sun rises from exact East, and sets at exact West (Note: the Sun reaches the zenith only for an observer on the equator)

2.6 Seasons and the calendar

Q: Where does the Sun rise and set?





- ✓ The Sun at C (*vernal equinox*) to E (*summer solstice*): it moves parallel to the celestial equator, but shifting northward.
- ✓ After *summer solstice* (E), the Sun shifts southward.

2.6 Seasons and the calendar

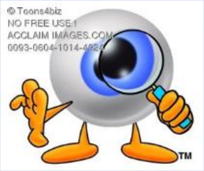
Calendar

- ✓ *Tropical year*: time required for Sun to return to the vernal equinox, ~ 365.2422 mean solar days
- ✓ The digits are close to 1/4, but not exact. Therefore, the *Gregorian calendar* has complicated rules of leap year to fit integral number of days into a year.

2.7 Brightness of celestial bodies

Luminosity: light power emitted (unit: W)

Distance r



Brightness: light power received per unit area (unit: W m^{-2})

2.7 Brightness of celestial bodies

- ✓ Luminosity (光度): the total radiation energy per unit time emitted by the star (unit: W).
- ✓ Brightness (亮度): The amount of light energy *received* per unit time per unit area. Thus, it depends on the luminosity of the star and the distance to the observer (unit: W m^{-2}).

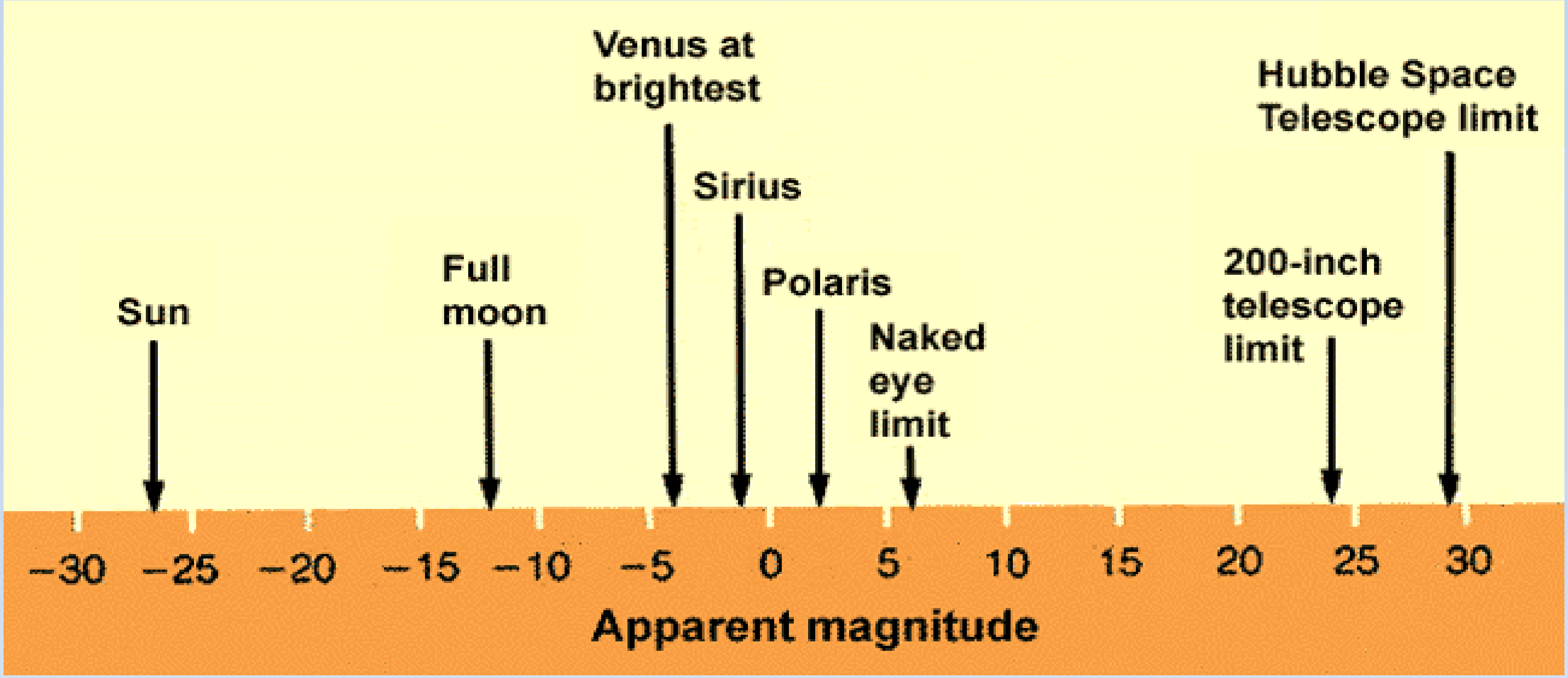
2.7 Brightness of celestial bodies

- ✓ Magnitude scale: logarithmic scale to measure the brightness of star
- ✓ lower magnitude refers to higher brightness. E.g., a star of magnitude 1 is brighter than that of 2; a mag -1 star is brighter than a mag 0 star.
- ✓ a difference of 1 in magnitude refers to an intensity ratio ≈ 2.5

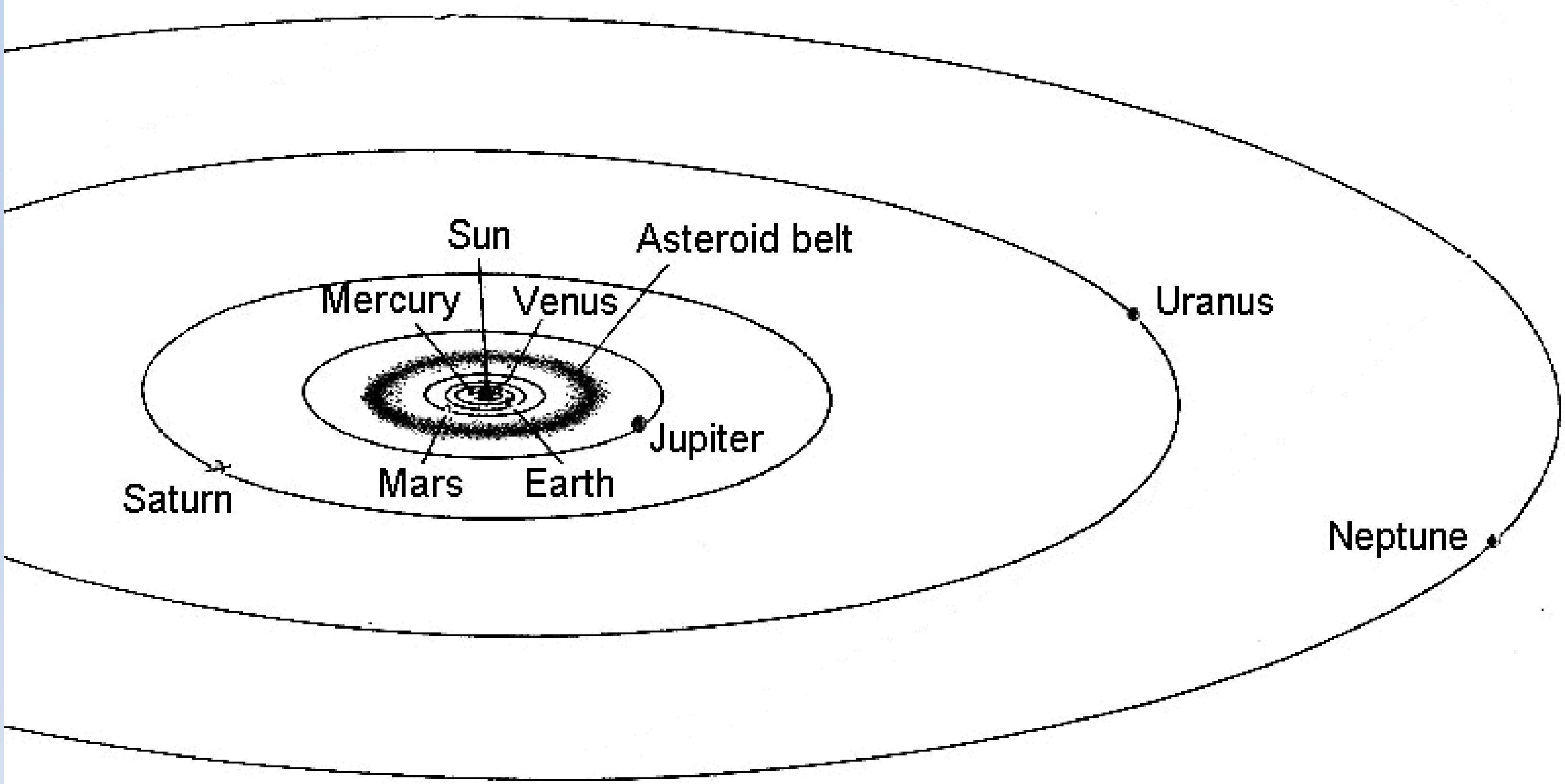
2.7 Brightness of celestial bodies

- ✓ Apparent magnitude (m, 視星等): measures the brightness of a star; $m = 0$ for Vega (織女星) by convention; apparent magnitude of the Sun is -26.
- ✓ Absolute magnitude (M, 絕對星等): Magnitude *as if* the objects were placed at a distance of 10 pc from the Earth, thus measures its luminosity, e.g., the absolute magnitude of the Sun is 4.8.
- ✓ $m - M = 5\log r - 5$ (where r is in parsec)

2.7 Brightness of celestial bodies

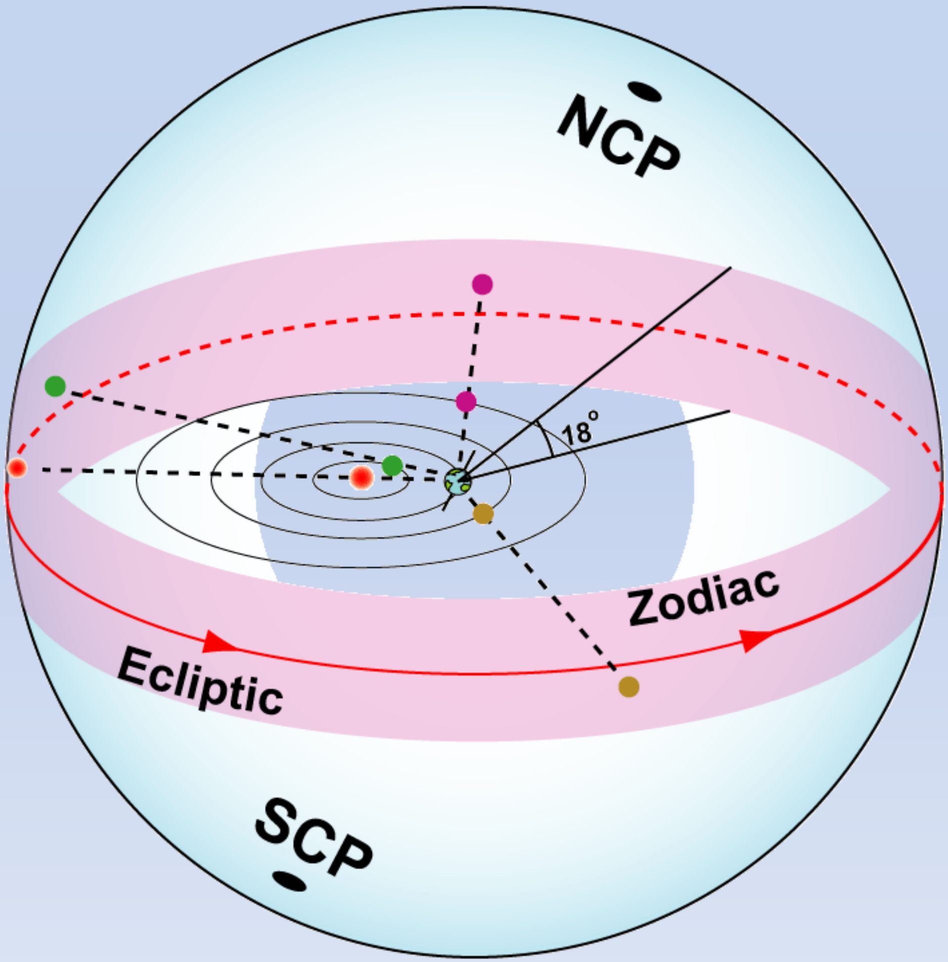


2.8 Planets



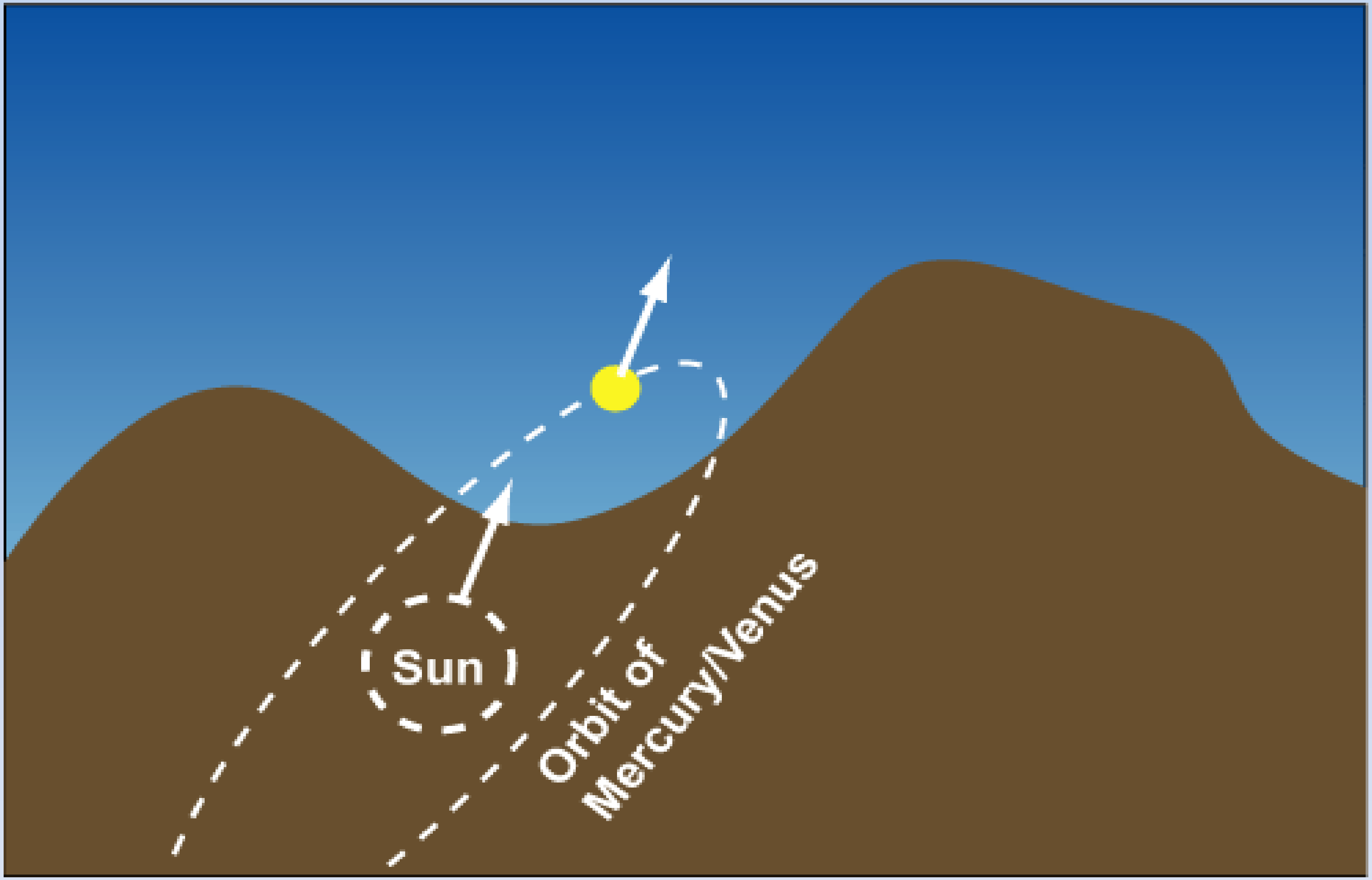
- ✓ The orbits of all the eight planets lie nearly on the same plane as the Earth's, except Mercury (7°).

2.8 Planets



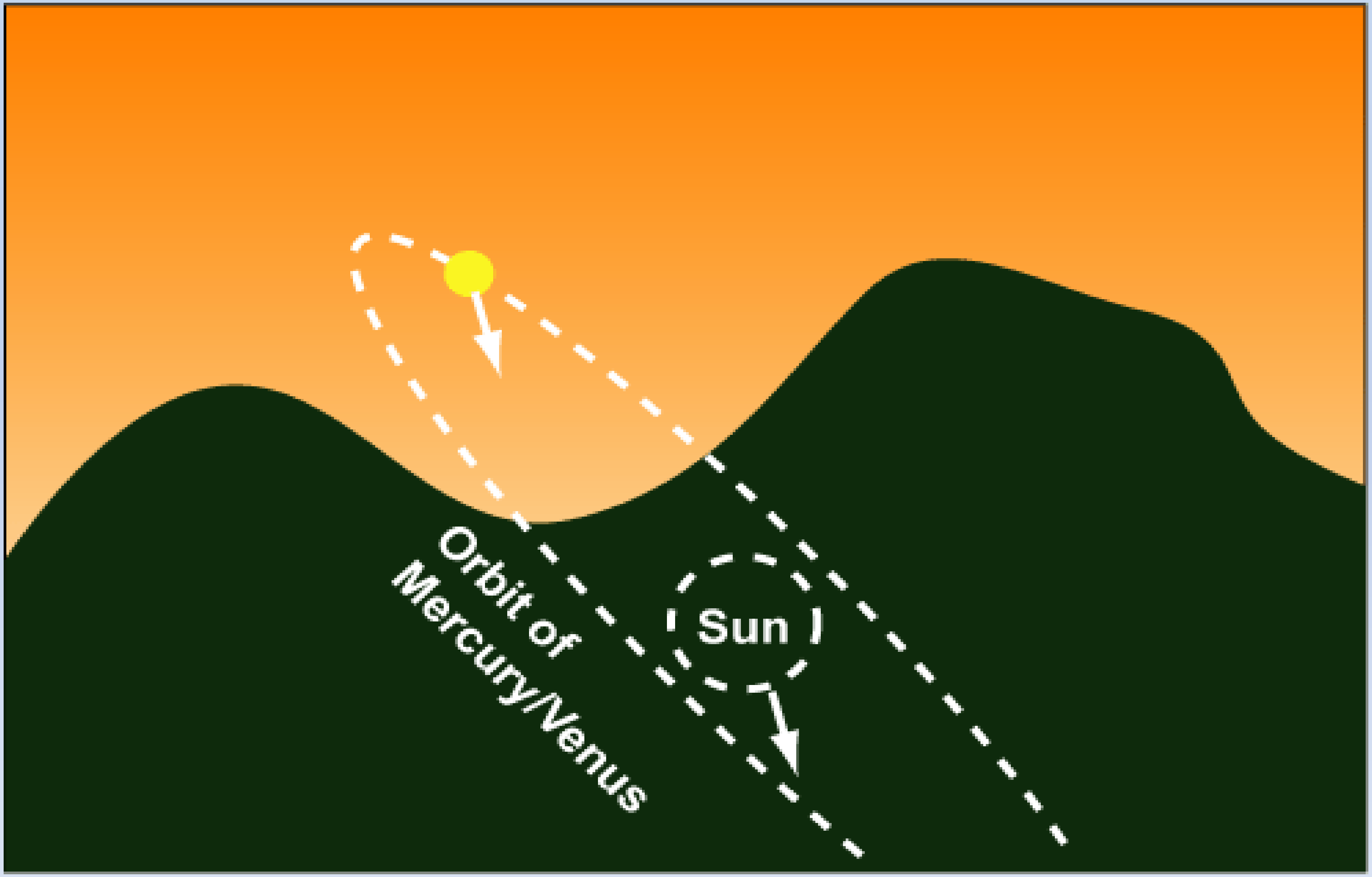
- ✓ Planets move in *zodiac* (黃道帶): a band of width 18° centered on the ecliptic
- ✓ Planets closer to the Sun move faster and have shorter orbital periods (Kepler's laws; more in Chapter 4)

2.8 Planets



✓ Inferior planets appears as either morning stars…

2.8 Planets



✓ … or evening stars.

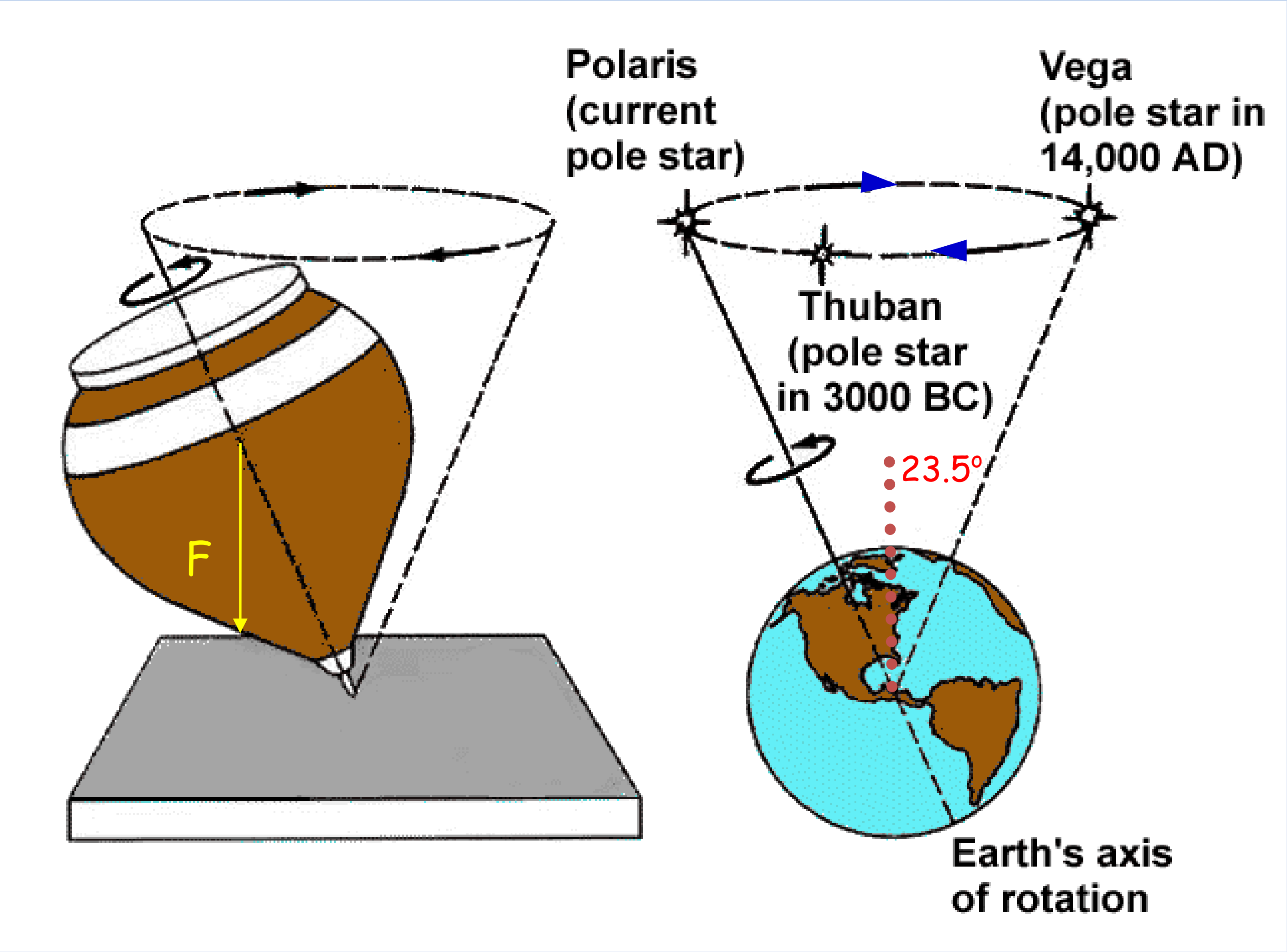
2.9 Precession

The pole star Polaris

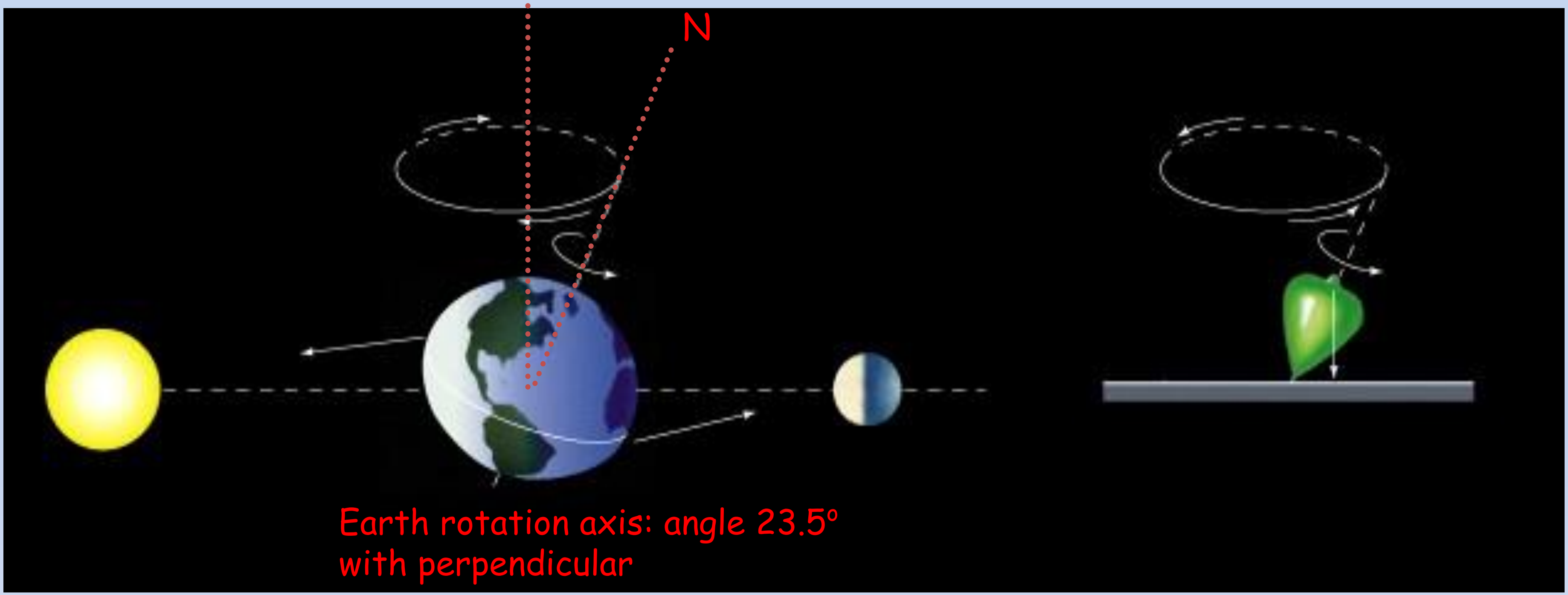
2.9 Precession

- ✓ The pole star changes over time. 5000 yrs ago, the celestial pole was near Thuban (天龍座 α).

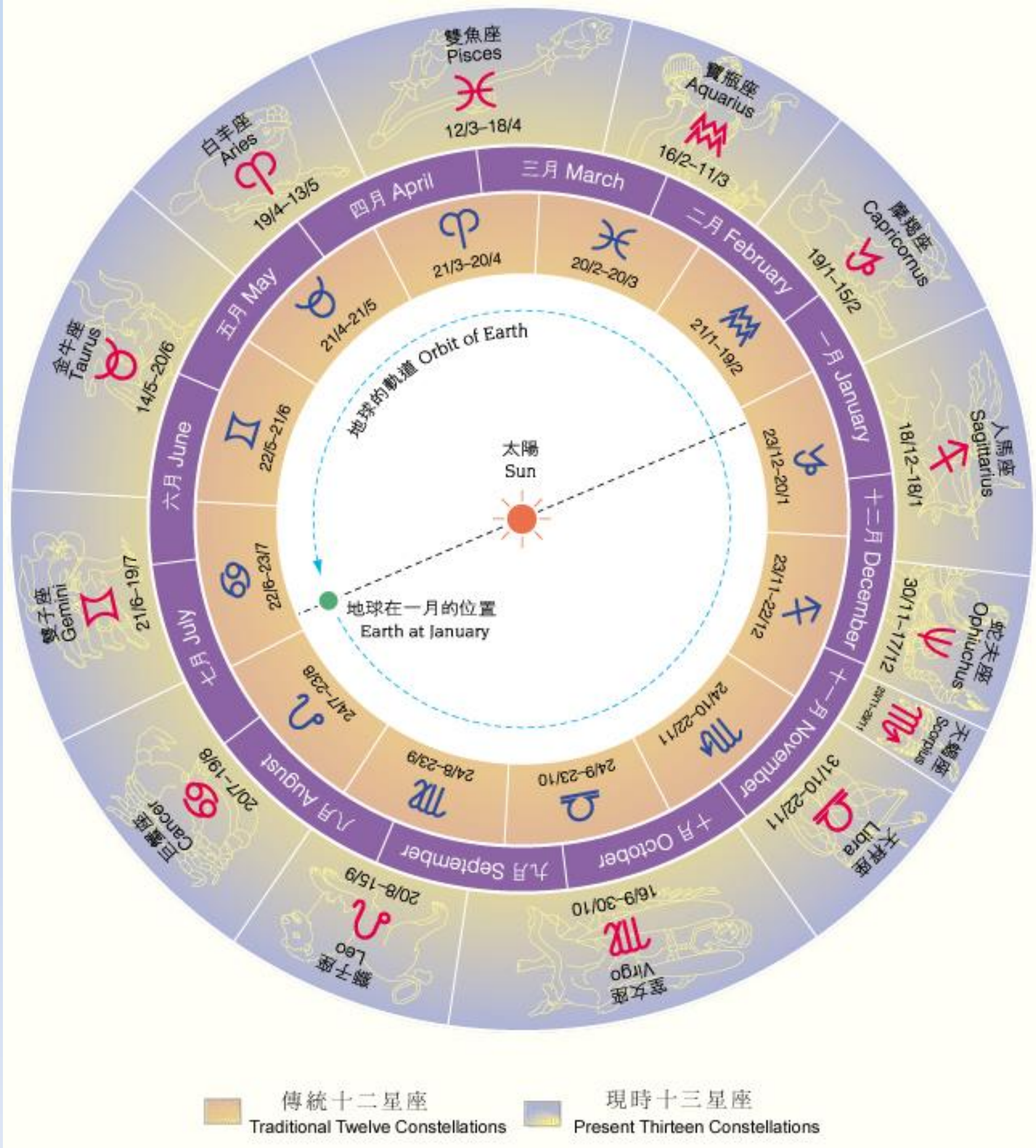
2.9 Precession



2.9 Precession



- ✓ Mainly due to gravitational attraction by the Moon and Sun on the bulged Earth: Precession
- ✓ The axial precession rate is about 50″ per year, with a cycle of about 26000 years.
- ✓ The equinoxes also shifts relative to distant stars


雙魚座
Pisces
12/3–18/4
寶瓶座
Aquarius
16/2–11/3
摩羯座
Capricornus
19/1–15/2
人馬座
Sagittarius
18/12–18/1
蛇夫座
Ophiuchus
30/11–17/12
天蠍座
Scorpius
31/10–22/11
Libra
16/9–30/10
Virgo
20/8–15/9
Leo
20/7–19/8
Cancer
雙子座
Gemini
21/6–19/7
金牛座
Taurus
14/5–20/6
白羊座
Aries
19/4–13/5
三月 March
二月 February
一月 January
十二月 December
November
十月 October
九月 September
八月 August
七月 July
六月 June
五月 May
四月 April
21/3–20/4
20/2–20/3
21/1–19/2
23/12–20/1
23/11–22/12
24/10–22/11
24/9–23/10
24/8–23/9
24/7–23/8
22/6–23/7
22/5–21/6
21/4–21/5
地球的軌道 Orbit of Earth
太陽
Sun
地球在一月的位置
Earth at January
傳統十二星座
Traditional Twelve Constellations
現時十三星座
Present Thirteen Constellations