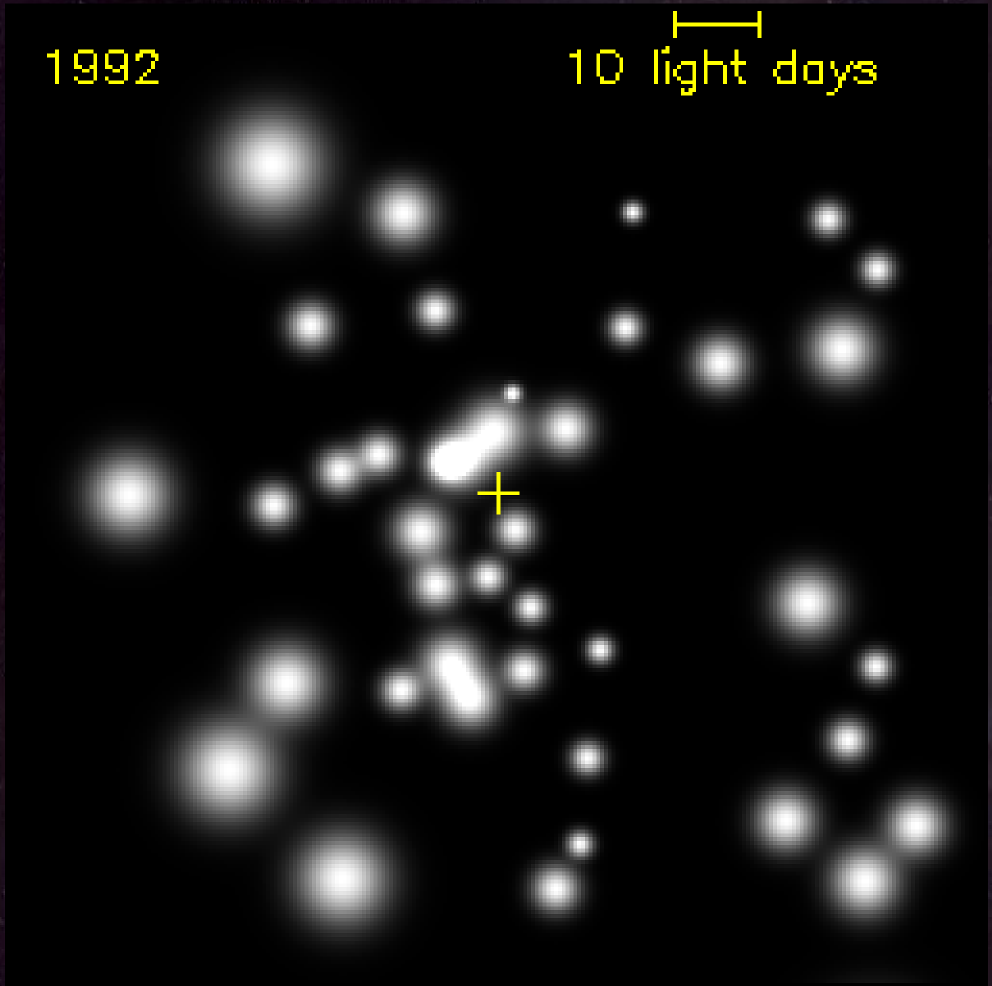
Active galaxies

Many galaxies contain vast amounts of matter (millions of times the mass of the Sun) in a very small region at their core (perhaps only a few light-hours across. Our galaxy is one such galaxy.



Active galaxies

You can see that whatever is at the centre of the Milky Way is not emitting any visible light.

It is thought to be a *black hole* – an object so massive that even light cannot escape its gravity.

Often, material orbiting a black hole gets so hot that emits extreme amounts of radiation.

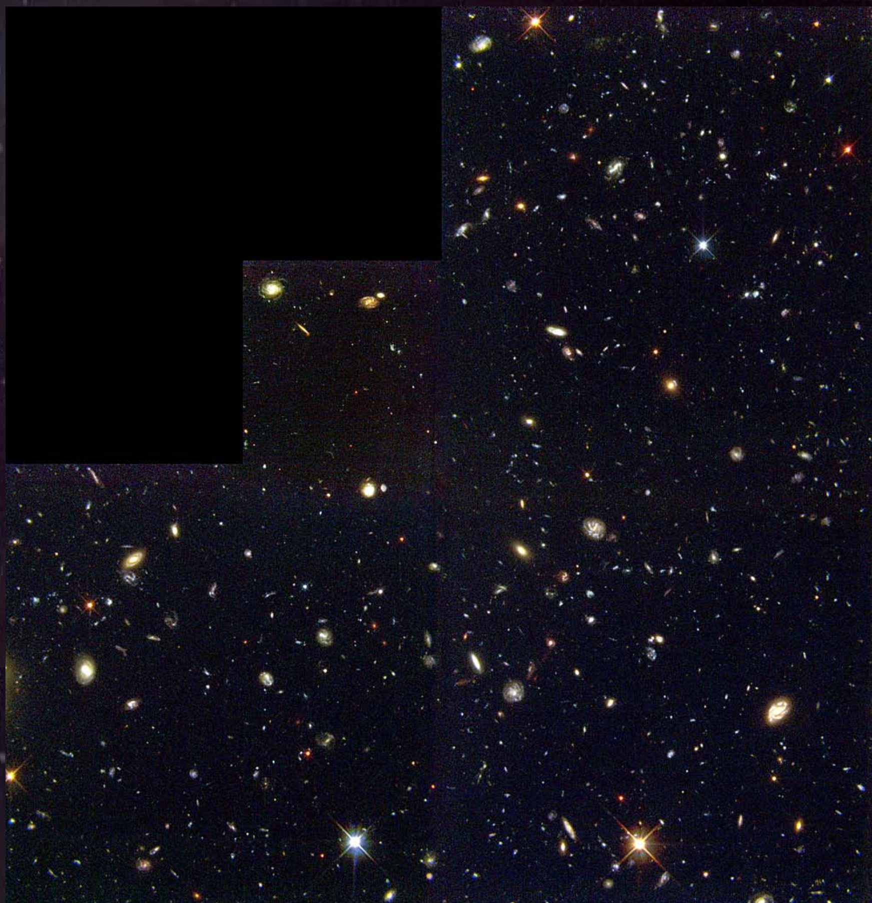
Quasars (*Quasi-stellar objects*) are some of the most luminous objects in the universe, and are powered by black holes.

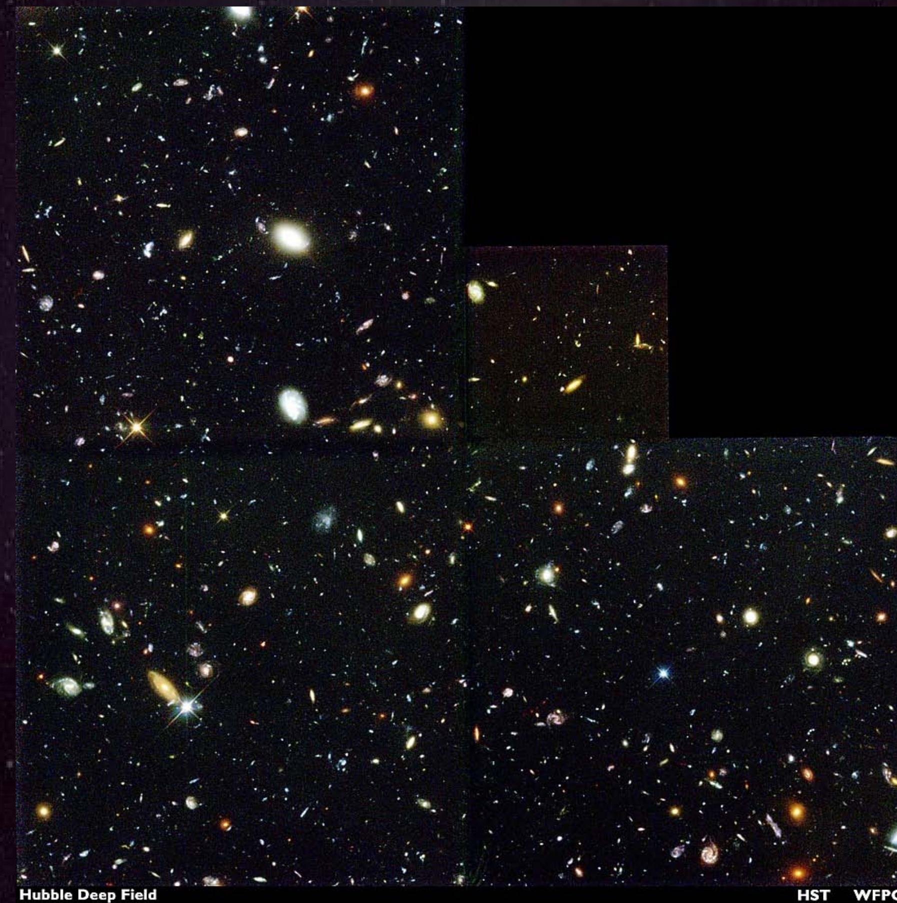
The distant universe

Galaxies exist in clusters, clusters are members of super-clusters, super-clusters are members of filaments. But at the very largest scales the universe looks pretty uniform.

It is generally thought that the universe at the very largest scales is *homogenous* and *isotropic* – that is, it looks the same in all directions and at all places. This is the *Cosmological Principle*.

The Hubble Deep Fields





Extremely deep images of two very small patches of sky, each 2.5 arcminutes across. They look very similar, supporting the cosmological principle.

The Big Bang

In the 1920s, Edwin Hubble discovered that all galaxies were receding from Earth. Tracing the expansion back implies that the universe had a beginning, and that beginning was about 15 billion years ago.

Fred Hoyle famously objected to the idea of the universe having a beginning, and derisively referred to the notion as the 'Big Bang theory'. That name stuck.

In 1964, Penzias and Wilson detected microwave emission that was coming from all parts of the sky with equal intensity. It was characteristic of a black body with a temperature of 2.7K

The Big Bang

This *Cosmic Microwave Background Radiation* was exactly what the Big Bang Theory had predicted, and provides almost unassailable evidence that there was a big bang.

Further evidence comes from the amounts of Helium and Lithium in the universe, which are well predicted by Big Bang theory, and the large-scale structure of the universe. Large simulations of how a universe would evolve if it started with a Big Bang give results that look very much like what is observed.

Finally, some types of object are seen in the distant universe but not nearby, ruling out any kind of 'steady state' universe

'Light' and the electromagnetic spectrum

Every picture I've shown so far has been taken in visible light. This is just one form of radiation, defined by what the human eye can perceive.

Outside the range of our perception, other types of radiation exist that we cannot observe directly.

Beyond the violet is *ultraviolet, x-rays* and *gamma rays.* Beyond the red is *infra-red, microwaves* and *radio waves*

We will discuss this more in subsequent lectures, but it's important to realise that visible light does not tell the whole story.

Today's lecture

Last week covered Chapter 1. Today we move on to Chapter 2.

We will discuss:

- The importance of astronomy to people throughout history
- The ways the sky changes over hours, years and centuries
- The seasons
- How positions in astronomy are measured
- How astronomy has led to most human concepts of time

Astrometry

As I mentioned last time, astronomy through the ages has largely been about measuring the positions of the stars – *astrometry*.

Many ancient structures relate to the positions of the star. Stonehenge is arranged to indicate where the Sun will rise at particular times of year. The Pyramids in Egypt, Angkor Wat in Cambodia, and Mayan, Aztec and Inca cities in Latin America all have astronomical purposes.

Constellations

Some aspects of ancient astronomy have been handed down through the ages and are still in use today. The most common is the notion of *constellations*.

The first map of the sky which divided it (arbitrarily) into sections called constellations was that of Ptolemy in the 2nd Century AD. Ptolemy's constellations are still in use today.

Other constellations are more recent inventions – particularly those in the southern hemisphere, which Ptolemy obviously never saw.

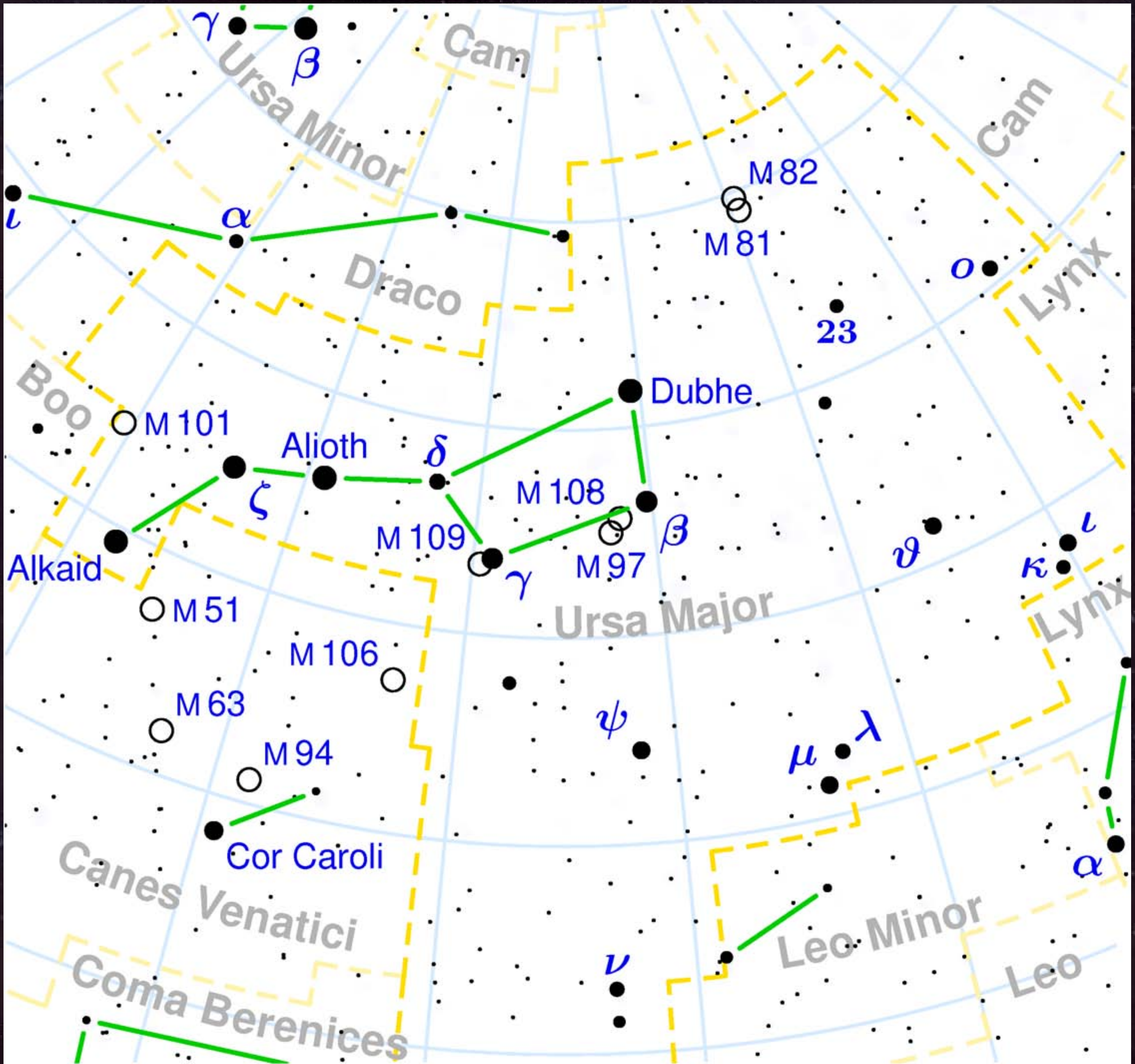
In total, there are 88 constellations. 47 are from Ptolemy, 41 are modern inventions.

Constellations

The constellations cover the whole of the sky. Some are large, some are small. Every part of the sky is in one constellation only.

Some constellations contain recognisable patterns of stars, like the Plough and Orion. But every star (and every object of any kind) within the constellation's boundaries is part of the constellation, and not just the recognisable pattern.

Constellations

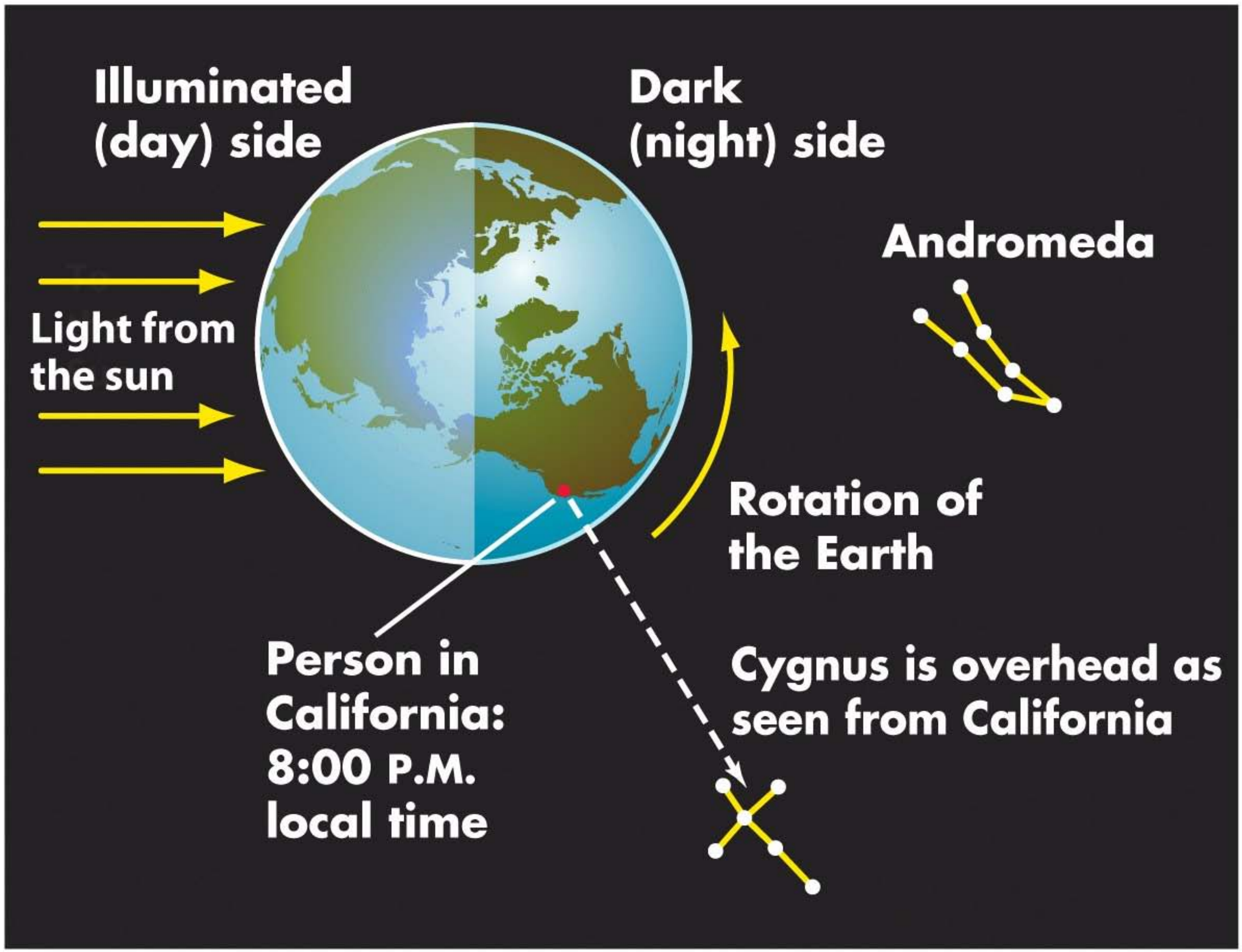


The changing sky

The night sky constantly changes in appearance, in different ways over different times, for different reasons.

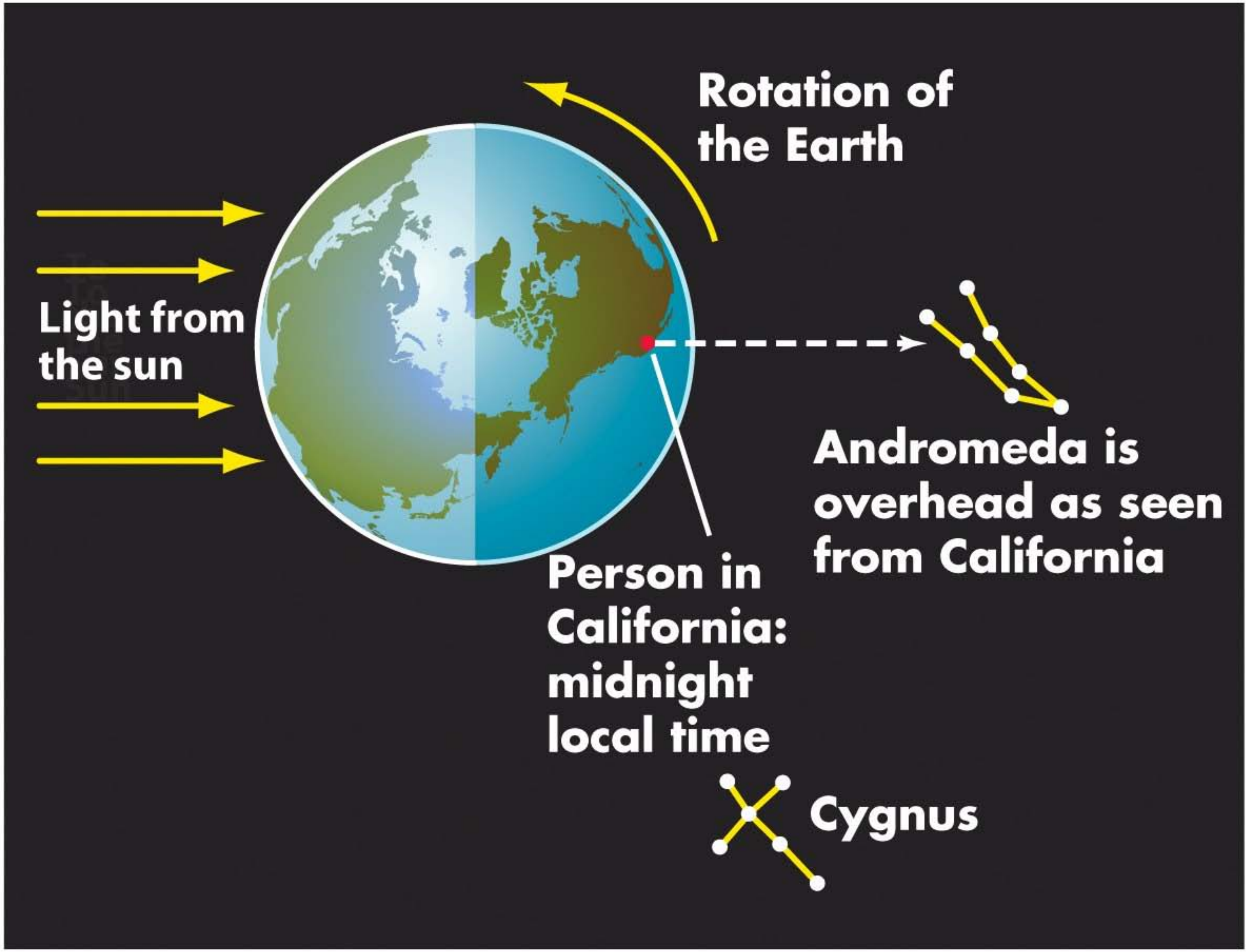
Over the course of a night, the stars appear to rotate around the sky. This is due to the rotation of the Earth.

The changing sky



(a) Earth as seen from above the North Pole

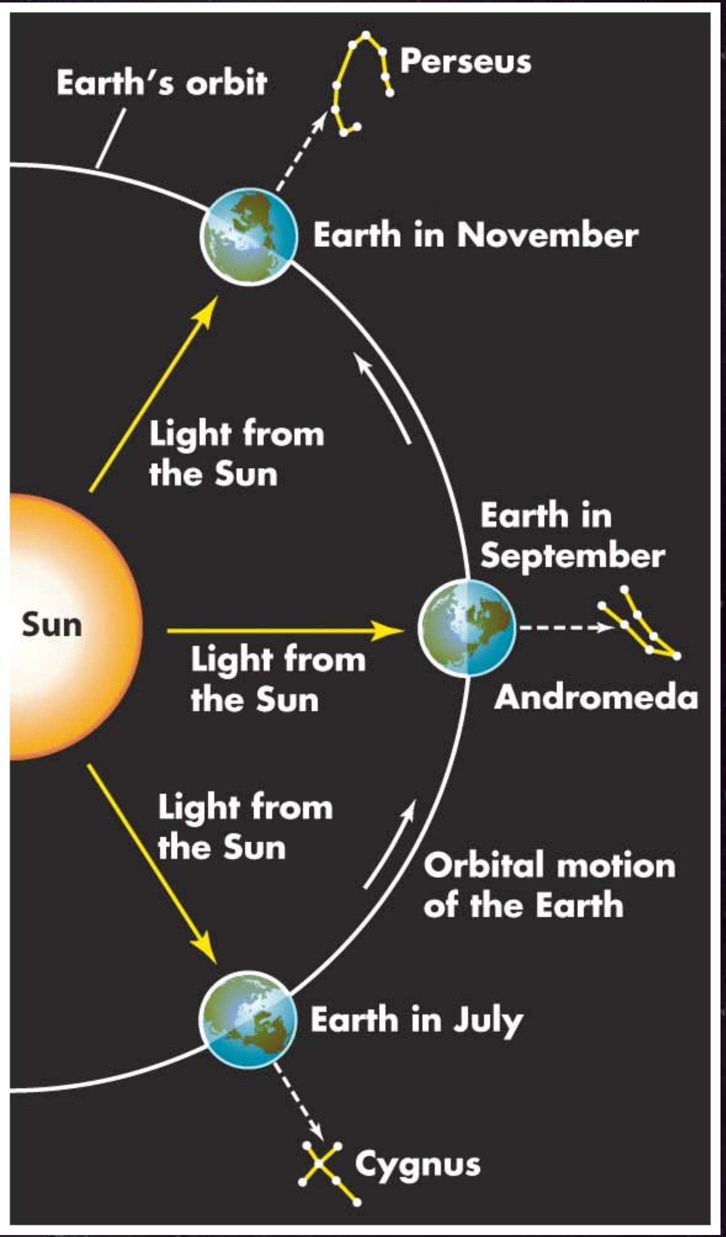
The changing sky



(b) 4 hours (one-sixth of a complete rotation) later

The changing sky

The stars also appear in a different place each night. A given star rises about four minutes earlier each night. This is due to the Earth's motion around the Sun.



The changing sky

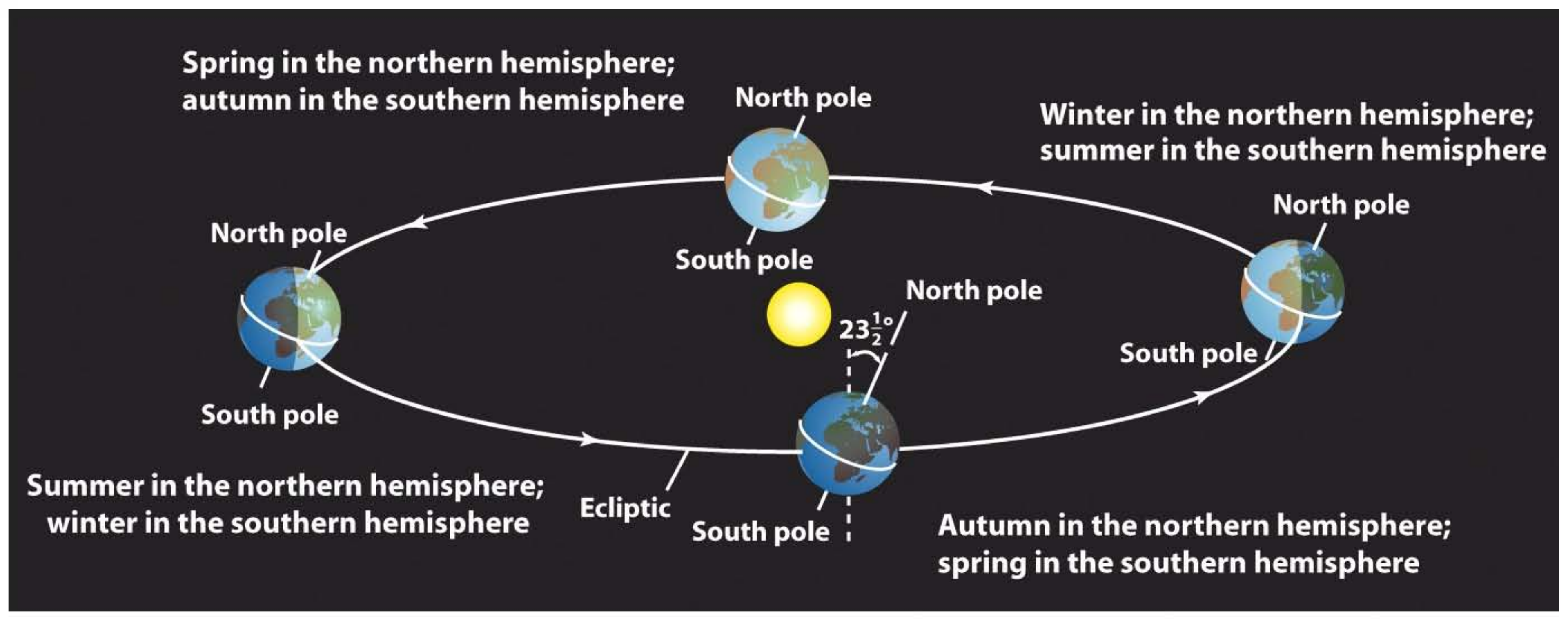
The celestial pole stays at a constant altitude throughout the night, and throughout the year. From temperate latitudes, the sky near the pole is constantly visible – it is said to be *circumpolar*.

The closer you are to one of Earth's poles, the more of the sky is circumpolar.

From the Earth's geographic poles, one entire hemisphere is circumpolar. From the equator, no part of the sky is circumpolar.

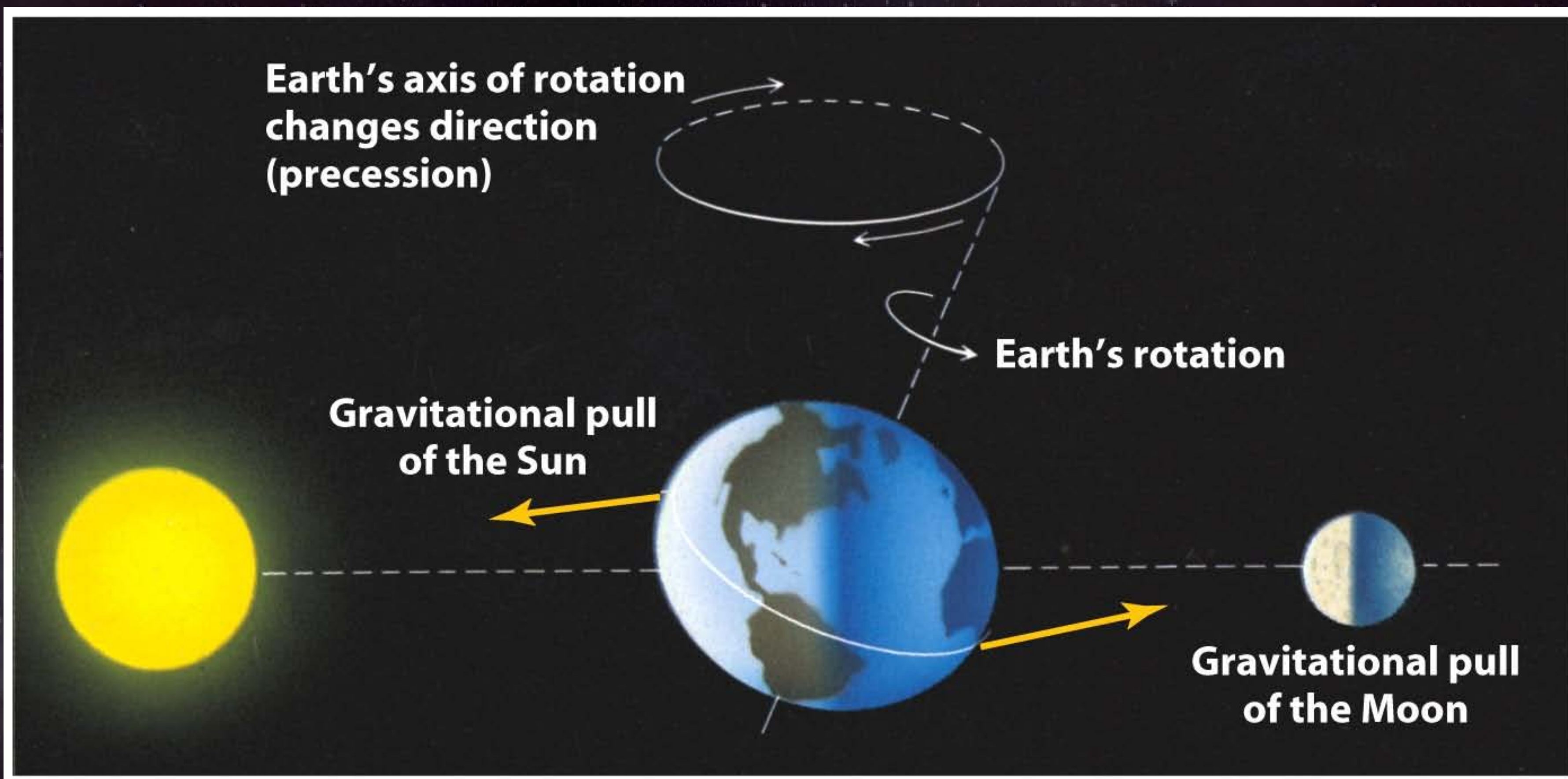
The changing sky

The Earth's rotational axis is inclined to the plane of its orbit around the Sun, by an angle of 23.5°.



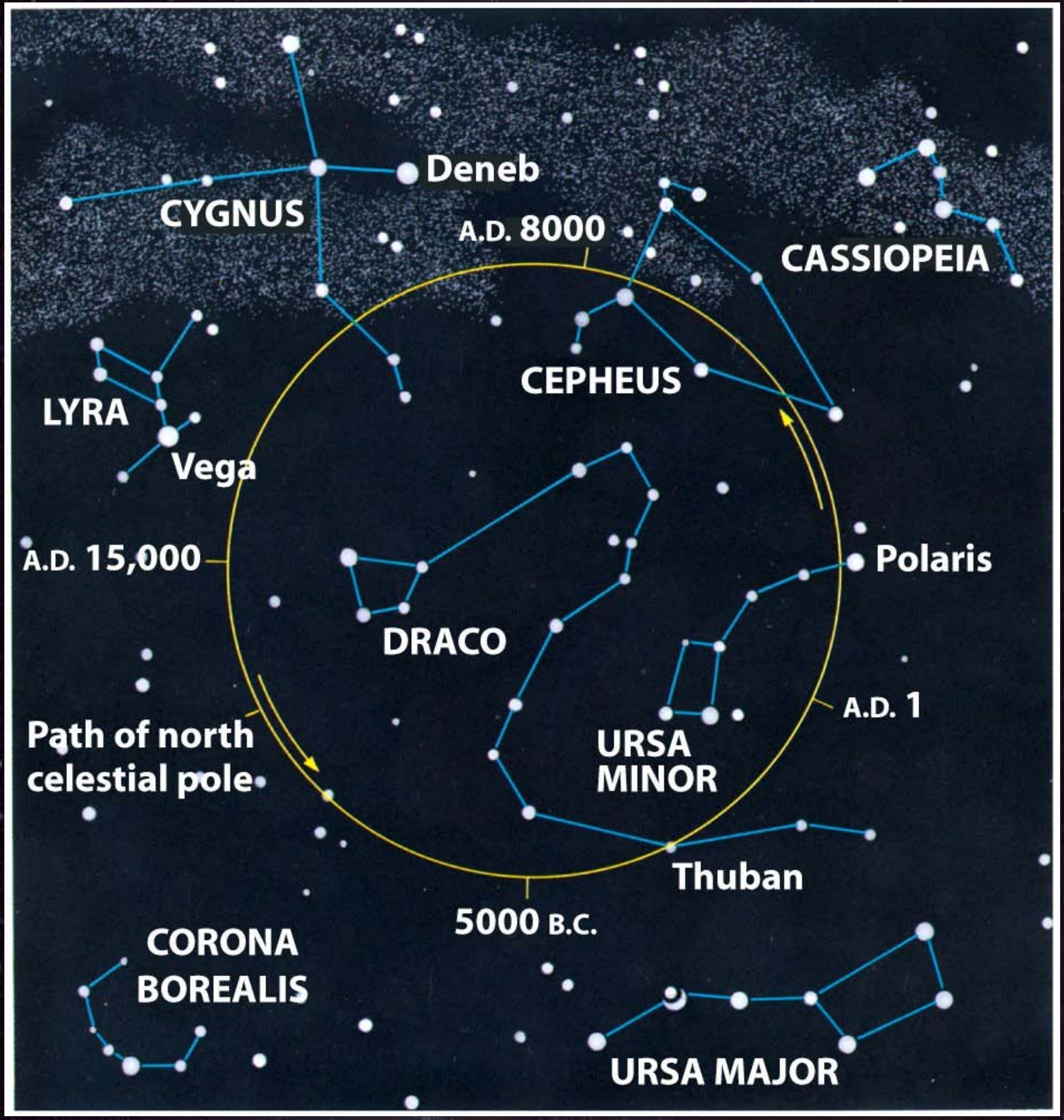
The changing sky

Earth is not quite a perfect sphere – it bulges at the equator. The gravitational pull of the Moon on the bulge causes the direction that the Earth's rotational axis points to change over thousands of years.



The changing sky

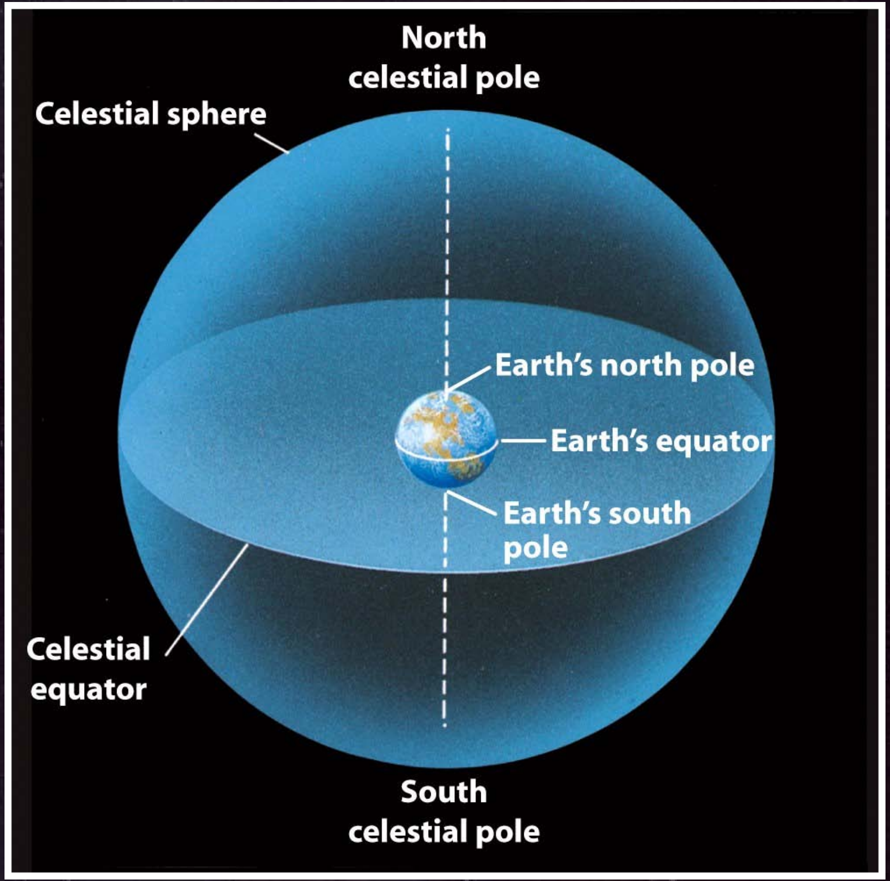
The position of the celestial pole moves around a circle every 26,000 years. This effect is called *precession*.



The celestial sphere

There is no perspective in the night sky – all things look equally distant. So we refer to the *celestial sphere*.

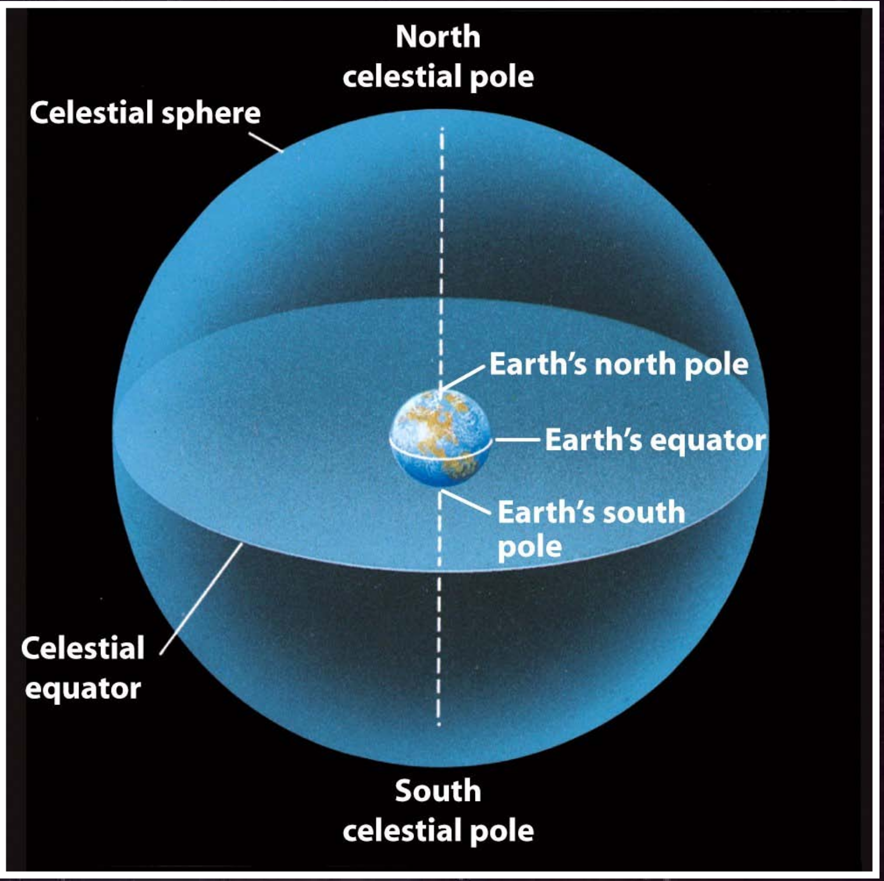
By analogy to longitude and latitude on the Earth, we can develop a convenient coordinate system for the night sky. The celestial poles are defined by the points in the sky towards which the Earth's poles point.



The celestial sphere

The *meridian* is the line joining North and South which passes directly overhead.

The celestial equator is the line equidistant from both celestial poles – exactly similar to the Earth's equator.



Right Ascension and Declination

The angle between the celestial equator and an object in the night sky is called its *declination* – similar to latitude on Earth's surface. Declinations are positive in the northern hemisphere and negative in the south.

The Pole Star, Polaris, has a declination of 89°15'51” - so it is not quite at true north, but it's close enough for navigation.

London is at a latitude of 51.5°N, and all objects with a declination larger than (90-51.5)=39.5° are circumpolar.

Right Ascension and Declination

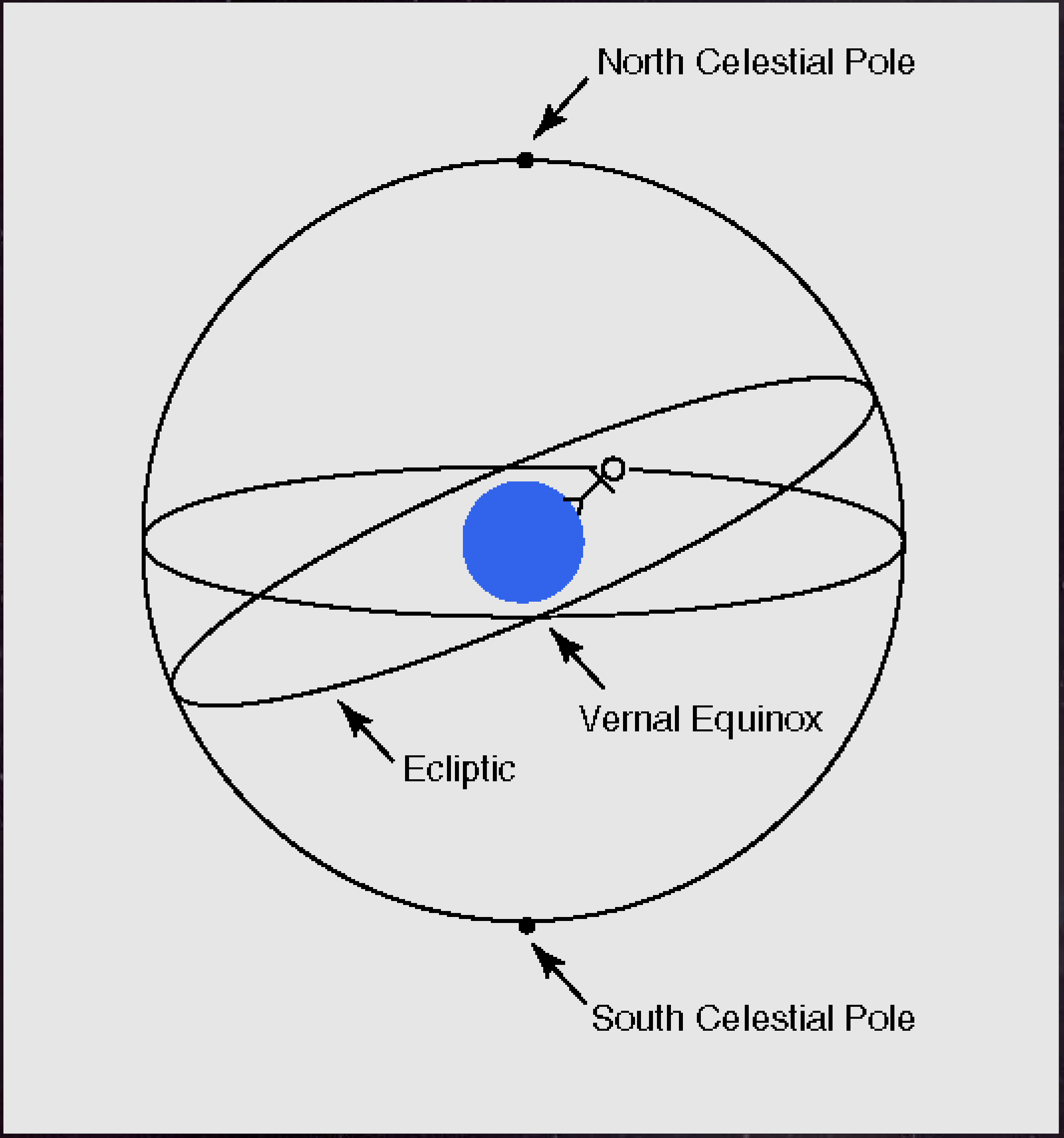
The celestial equivalent of longitude is called *Right Ascension*. (In)conveniently, it is not measured in degrees but in hours, minutes and seconds.

Longitude on Earth is arbitrarily defined as being zero in Greenwich. Similar on the sky, an arbitrary point needs to be defined as having a Right Ascension of zero.

Because of the tilt of Earth's rotational axis, the Sun crosses the celestial equator twice a year – at the equinoxes. RA=0 at the point where the Sun crosses from the Southern hemisphere into the Northern hemisphere.

Right Ascension and Declination

The path the Sun moves along is called the *ecliptic*.



Right Ascension and Declination

The point at which RA=0 is called the *First Point of Aries.* But it does not lie in Aries.... because of precession, it has moved and is now in Pisces.

After the First Point of Aries has crossed the meridian, then the time until a given object will pass the meridian is equal to its Right Ascension.

So Right Ascension being in hours, minutes and seconds is convenient after all. But it is easy to confuse seconds of time in RA with seconds of arc in declination.

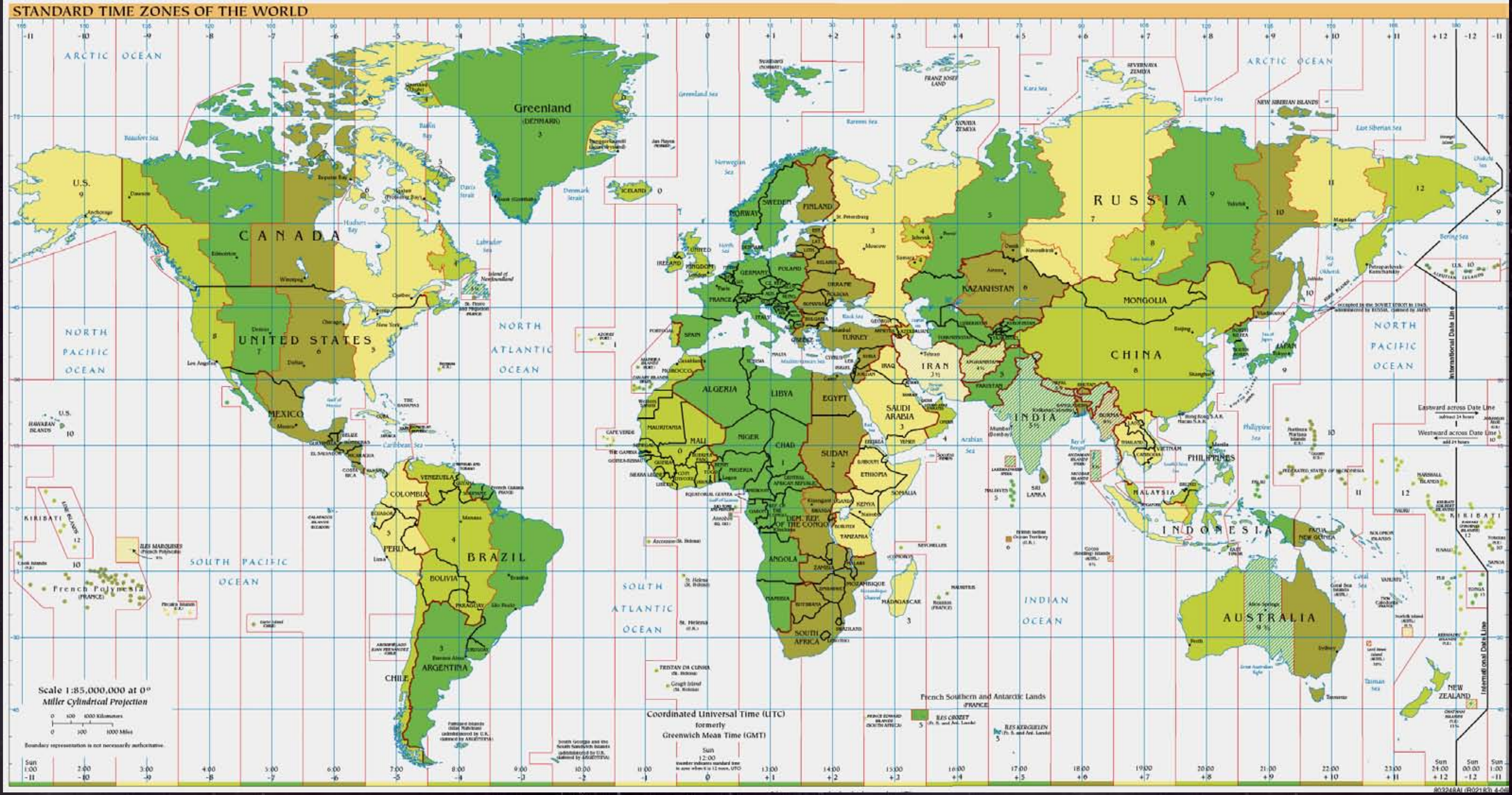
Solar Time

Solar time is what we are all used to. In solar time, one day is defined as the interval between successive occasions on which the Sun lies directly due south (or north, in the southern hemisphere).

Local Solar Time is seldom used – too inconvenient to worry about the ten minute difference between local noon in London and local noon in Bristol, for example.

So the Earth is divided into time zones, generally 15 degrees of longitude wide. These mean that local noon is generally within an hour of actual solar noon.

Solar Time


STANDARD TIME ZONES OF THE WORLD
ARCTIC OCEAN
Greenland (DENMARK)
CANADA
UNITED STATES
MEXICO
NORTH PACIFIC OCEAN
NORTH ATLANTIC OCEAN
SOUTH PACIFIC OCEAN
SOUTH ATLANTIC OCEAN
INDIAN OCEAN
BRAZIL
ARGENTINA
CHILE
PERU
COLOMBIA
BOLIVIA
VENEZUELA
RUSSIA
CHINA
MONGOLIA
KAZAKHSTAN
INDIA
IRAN
SAUDI ARABIA
EGYPT
LIBYA
ALGERIA
SUDAN
CHAD
NIGER
MALI
ANGOLA
SOUTH AFRICA
AUSTRALIA
INDONESIA
PHILIPPINES
JAPAN
NEW ZEALAND
International Date Line
Eastward across Date Line subtract 24 hours
Westward across Date Line add 24 hours
Coordinated Universal Time (UTC) formerly Greenwich Mean Time (GMT)
Scale 1:85,000,000 at 0°
Miller Cylindrical Projection
Boundary representation is not necessarily authoritative.

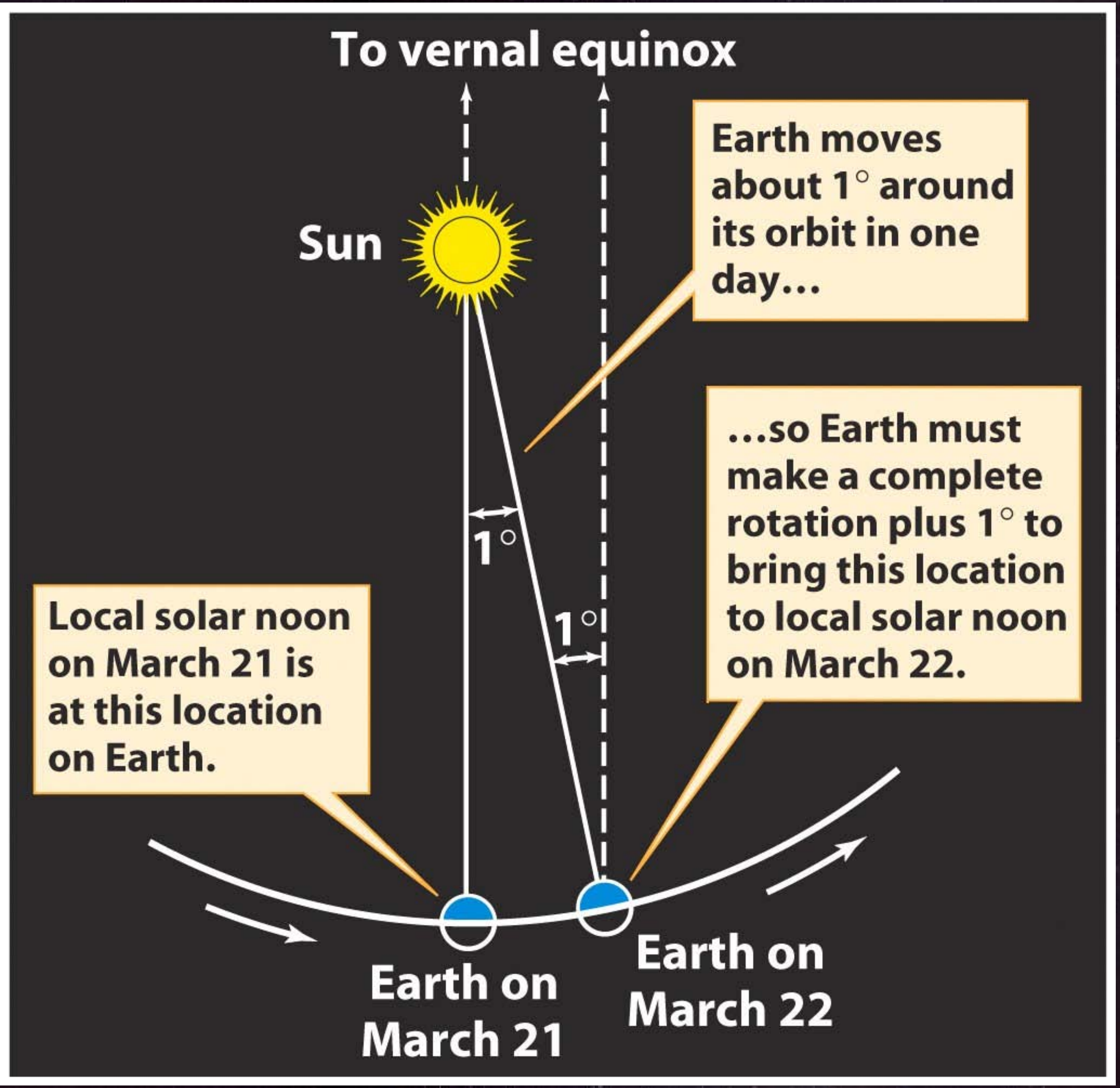
Sidereal Time

In astronomy, we often use *sidereal time* – this is the time measured from the stars, rather than the Sun.

Because the Earth is orbiting the Sun, a solar day is slightly longer than a sidereal day. A given star rises about four minutes earlier every day.

One Sidereal Day is defined as the interval between successive occasions on which a star lies directly due south.

Sidereal Time



Sidereal Time and Right Ascension

Sidereal time = 0:00:00 when the First Point of Aries crosses the meridian. Sidereal time = Solar time = 0:00:00 only once a year, at the autumnal equinox.

For any object in the sky, it will be highest in the sky, and therefore most observable, when the sidereal time is equal to its Right Ascension. So, an object with a Right Ascension of 0h is best observed in September, when it will be highest in the middle of the night.

The same object in March will be highest in the sky during the daytime and therefore not observable.

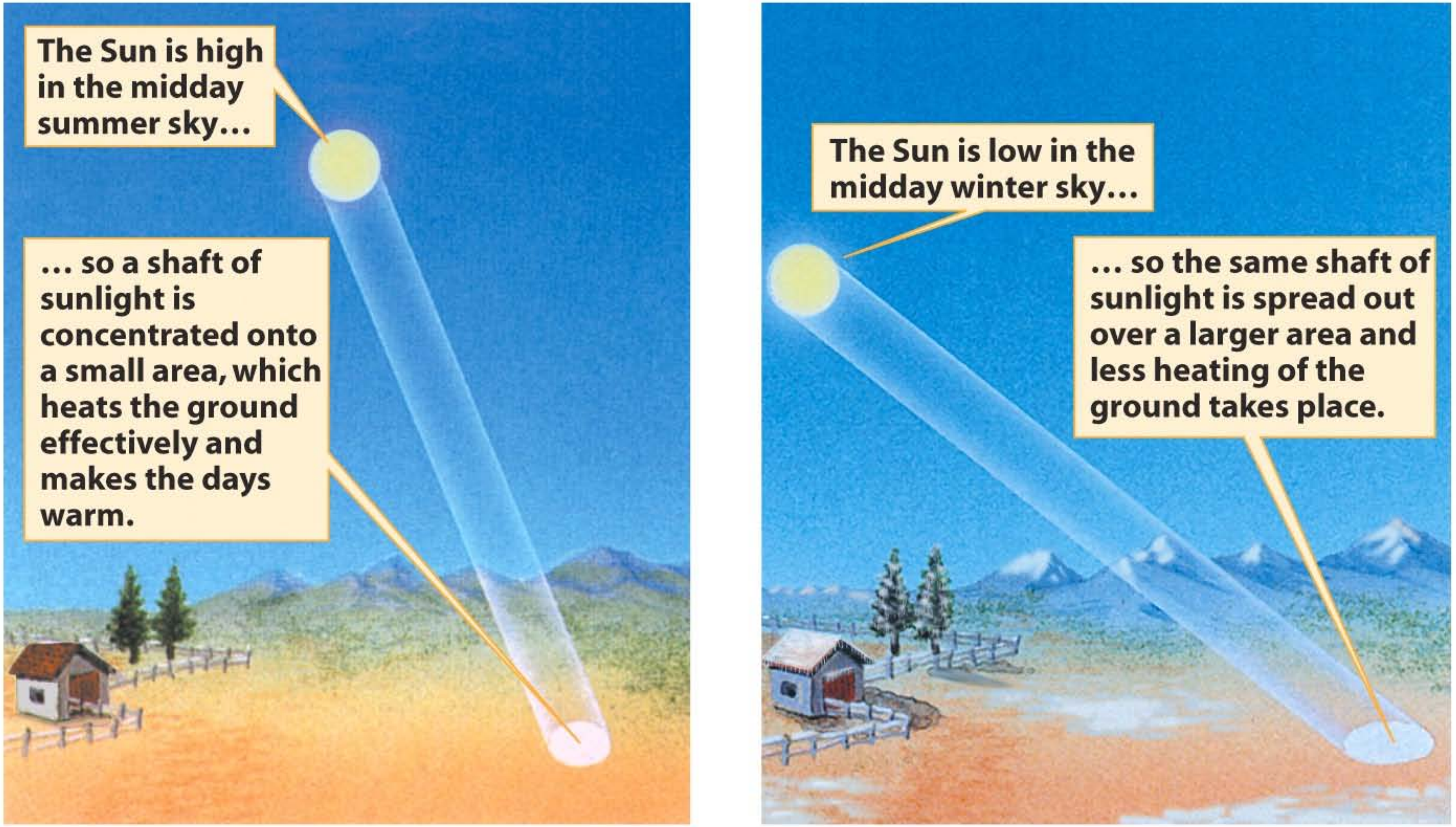
Seasons

I mentioned earlier that the Earth's rotational axis is tilted relative to the plane of its orbit. This tilt causes the seasons – the regular change in weather patterns over the course of a year.

Each hemisphere spends six months enjoying longer days than nights, and during this time the sun is higher in the sky.

The higher the Sun in the sky, the more energy strikes a given area. The combination of longer daylight hours and more direct sunlight results in higher temperatures.

Seasons



(a) The Sun in summer (b) The Sun in winter

Seasons

The Earth's orbit is elliptical: we are closest to the Sun in January (91.4 million miles away), and furthest away in July (94.5 million miles away).

The Earth moves faster when it is closer to the Sun. This means that the Northern hemisphere winter is slightly shorter than the Southern hemisphere winter.

But the effect of this on temperatures is insignificant. We only receive 6% more energy from the Sun in January than we do in July.

Astronomy and time

Astronomical observations led to the development of the modern calendar

The day is based on the Earth's rotation

The year is based on the Earth's orbit

The month is based on the Moon's orbit

Note 'based on', not 'equal to'! None of these quantities are exactly constant, so astronomers use the average or mean day and leap years to keep the calendar and time consistent

Leap Years

The Earth orbits the Sun in 365.2425 days. Therefore, the calendar year of 365 days drifts by 0.2425 days each year.

With an extra day every four years, the drift is reduced to -0.0075 days per year, or -0.75 days per century.

Century years are *not* leap years, unless they are also divisible by 400 (so 2000 *was* a leap year).

By missing three leap days every four centuries, the 0.75 days per century drift is corrected.

The tiny remaining drift will not need correcting for millennia yet.

Leap Seconds

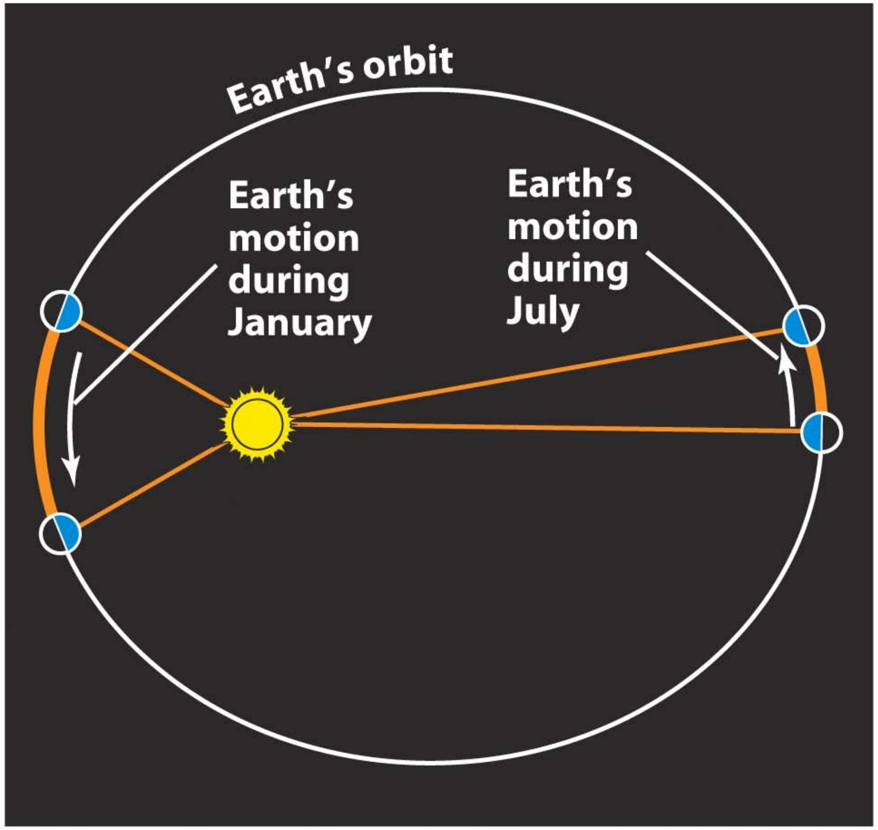
Leap seconds are occasionally added to Coordinated Universal Time – the international standard measure of time.

They are necessary because the Earth's rotation speed is not quite constant. It is slowing by 1.7 ms per century, and the length of the day now is very slightly different to what it was when the second was originally defined as a unit of time.

The length of the day can change for other reasons: the 2004 Indian Ocean tsunami caused the day to shorten by 0.00268 ms.

The 'Equation of Time'

The motion of the Sun across the sky is not uniform. It is faster in the northern hemisphere winter than it is in the summer. This is because the Earth's orbit is elliptical.



(a) A month's motion of the Earth along its orbit

The 'Equation of Time'

Days in our Winter are thus slightly shorter than 24 hours, while days in Summer are slightly longer than 24 hours.

This means that if you measured the exact time at which the Sun was due south every day, you would find that your 'clock' based on this was not quite accurate, running fast in the summer and slow in the winter.

Clocks are thus based on the *mean sun*, a hypothetical object moving at a uniform rate across the sky. The *equation of time* is the name given to the difference between the position of the mean sun and the actual sun.

The 'Equation of Time' and the analemma

The equation of time gives rise to the *analemma*. If you take a photo of the Sun at exactly the same time every day for a year, you will see that it follows a figure-of-eight path: