Course notes - reminder

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- `http://zuserver2.star.ucl.ac.uk/~rwesson/PHAS1511`

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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

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Astrometry

- 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. E.g. Stonehenge is arranged to indicate where the Sun will rise at particular times of year.

Constellations

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- Some aspects of ancient astronomy have been handed down through the ages and are still in use today - eg **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.

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- 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.

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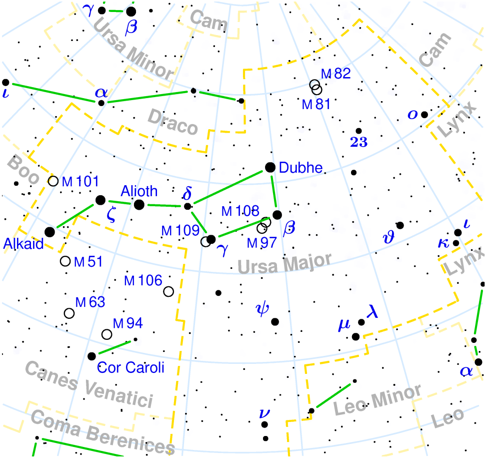
- The constellations cover the whole of the sky. Some are large, some are small. Every part of the sky is in one constellation only.
- Some constellations contain recognisable patterns of stars, like the Plough and Orion. But every star (and every object of any kind) within the constellation's boundaries is part of the constellation, and not just the recognisable pattern.

Constellations



The changing sky

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- 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.

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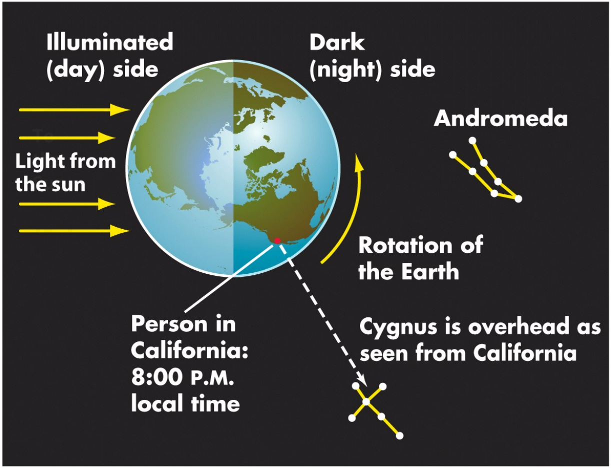

(a) Earth as seen from above the North Pole

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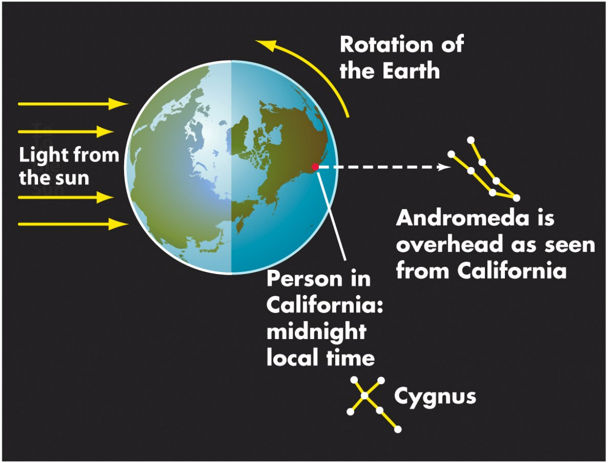
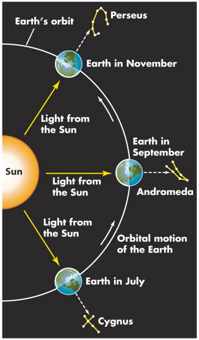
The changing sky



(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.



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- The celestial pole stays at a constant altitude throughout the night, and throughout the year. From temperate latitudes, the sky near the pole is always 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.

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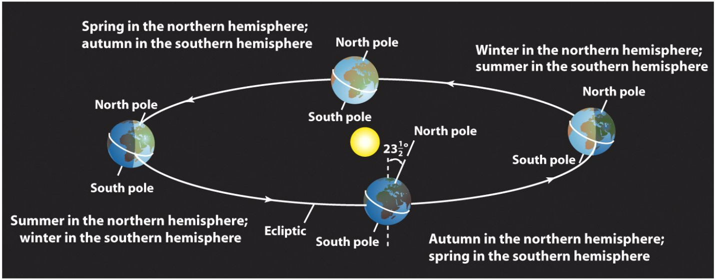
- The Earth's rotational axis is inclined to the plane of its orbit around the Sun, by an angle of 23.5.



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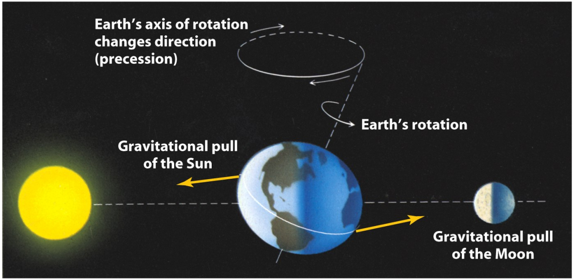
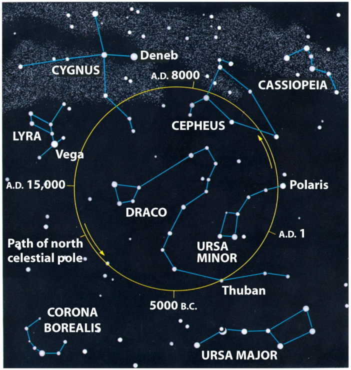
- Earth is not quite a perfect sphere – it bulges at the equator. The gravitational pull of the Moon on the bulge causes the direction that the Earth's rotational axis points to change over thousands of years.



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

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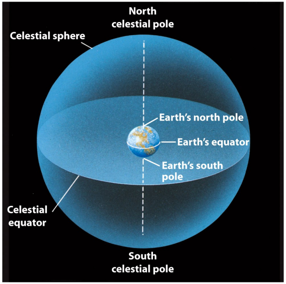
- There is no perspective in the night sky – all things look equally distant. So we refer to the **celestial sphere**.



- 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.

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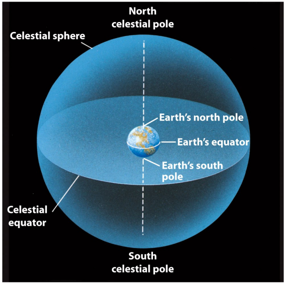
The celestial sphere

- 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.

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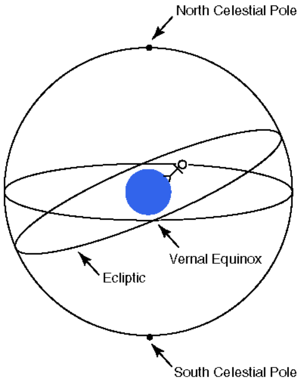
- The path the Sun moves along is called the **ecliptic.**



Right Ascension and Declination

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- 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 $89^o15'51$ - so it is not quite at true north, but it's close enough for navigation.
- London is at a latitude of 51.5N, and all objects with a declination larger than (90-51.5)=39.5 are circumpolar.

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- 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.

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- 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.

Right Ascension and Declination

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- Because of precession, this coordinate system constantly shifts.
- So RA and dec coordinates are always given for a particular *epoch*.
- Until 1984, coordinates were given for 1950. Since then they have been given for 2000.

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Right Ascension and Declination summary

- The **declination** of an object in the sky is its angular distance from the celestial equator.
- The Sun appears to move around the sky along a path called the **eclipt ic**, which is inclined at 23.5 degrees to the celestial equator because the Eart h's rotational axis is tilted by that amount.
- The **First Point of Aries** is the point where the ecliptic crosses the celestial equator.
- The **Right Ascension** of an object is the time in hours between when the First Point of Aries crosses the meridian, and when the object crosses the meridian.

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Right Ascension and Declination summary

- Because of the gravity of the Moon and Sun on the Earth's equatorial bulge, the direction in which the Earth's rotational axis points revolves with a period of 26,000 years.
- Hence, the First Point of Aries moves, and the Right Ascension of an object changes with time.
- So, the year in which the Right Ascension is correct must be specified. RAs are currently all given for 1 January 2000.

Solar Time

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- 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.

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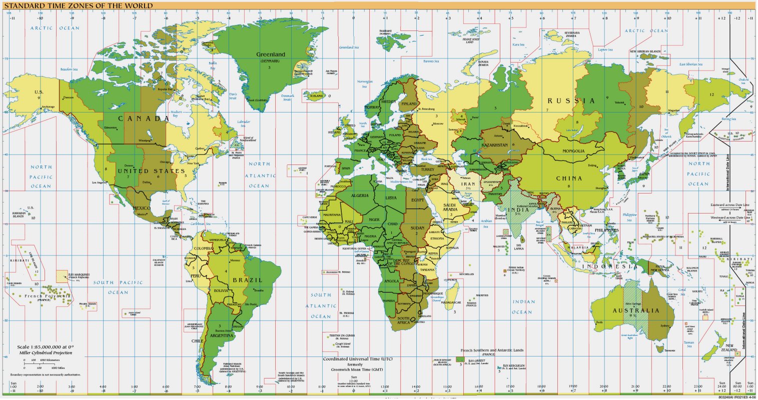
Solar Time



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- Astronomers 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.

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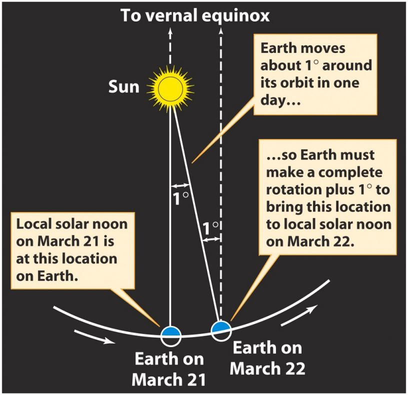

Sidereal Time and Right Ascension

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- 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.

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- 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.

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- 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

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- Astronomical observations led to the development of the modern calendar
- The day is based on the Earths rotation
  The year is based on the Earths 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

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- 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 leap years, unless they are also divisible by 400 (so 2000 wasa 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 Years – a historical digression

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- The current leap year rules form the basis of the **Gregorian Calendar**. This replaced the **Julian Calendar**, in which every fourth year was a leap year.
- The Julian calendar slowly drifted relative to the seasons. On the adoption of the Gregorian Calender in Britain in 1752, the large drift accumulated over 1500 years was corrected by skipping straight from Wednesday 2 September to Thursday 14 September.
- Nobody rioted! Seems to be a historical misconception.

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Leap Years – a historical digression

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- England in 1750 was viciously anti-catholic. So, adopting the 'popish' calendar was a controversial political issue. Hogarth was depicting election campaigning, not public rioting.
- Russia did not adopt the Gregorian Calendar until 1922. So, the revolution that happened on 7 November 1917 in the Gregorian Calendar is called the October Revolution.

Leap Seconds

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- 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.

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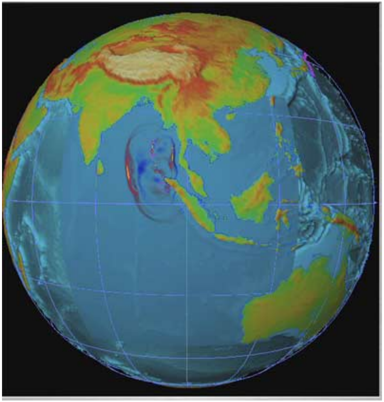
- The length of the day can change for other reasons: the 2004 Indian Ocean tsunami caused the day to shorten by 0.00268 ms.



The 'Equation of Time'

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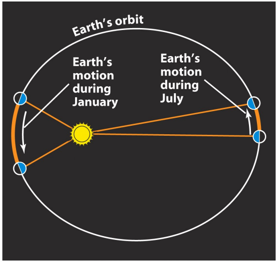
- The motion of the Sun across the sky is not uniform. It is faster in the northern hemisphere winter than it is in the summer. This is because the Earth's orbit is elliptical.



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

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- 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

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- 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: