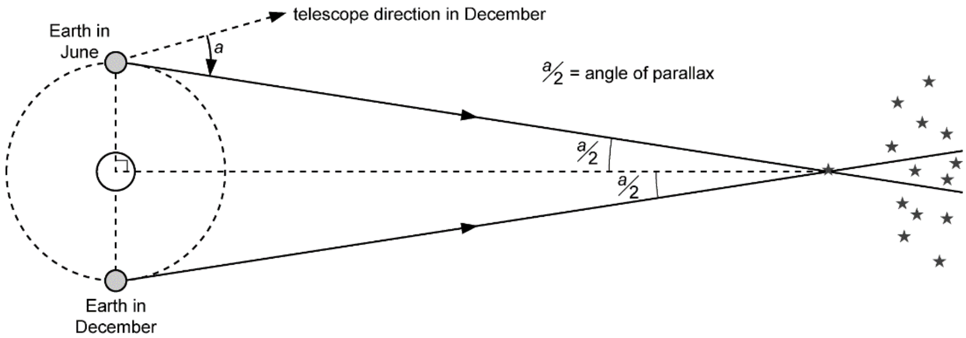
Measuring the Universe SA Notes

Describe and explain evidence for a 'hot big bang' origin of the universe from cosmological red-shifts (Hubble's law) and cosmological microwave background. Make calculations and estimates of distances and ages of astronomical objects.

Within the solar system radar can be used to measure distance. Outside the solar system the trip time for radar is way too long, over 8 years for the very nearest star. Also, as the radar beam travels it spreads out so its intensity falls. The returning signal would be far too weak to detect. Other ways of measuring distance are needed.

Parallax Measurements

Stellar parallax measurements using satellites such as GAIA can measure the distance to stars within our own galaxy, the Milky Way. As the Earth orbits the Sun the position of stars changes slightly due to parallax. If the angle of the change is measured the distance can be calculated.



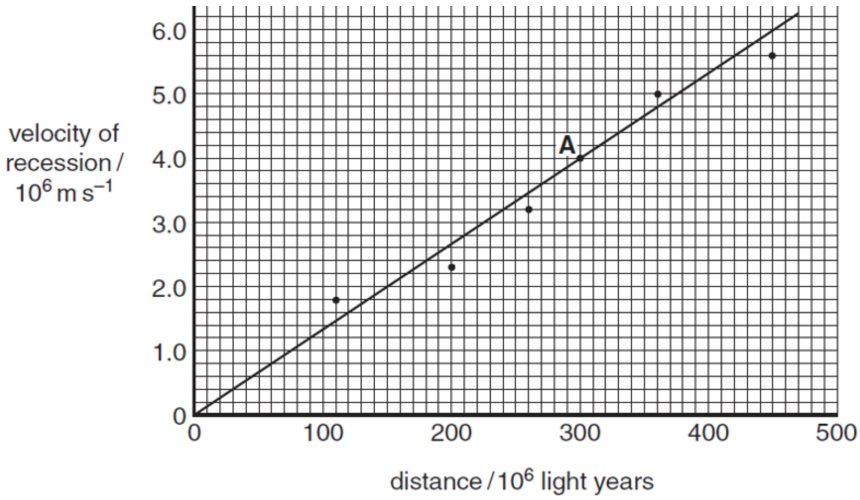
distance in parsec = 1/angle in arc sec

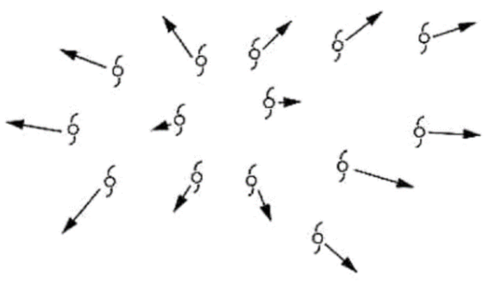
Hubble's Law

For other galaxies parallax angles are too small to measure – a new method is needed. The distance to a galaxy can be established by using a 'standard candle' - a source of known luminosity such as a Cepheid variable star or a type 1a supernova. By knowing the actual luminosity of this object in the distant galaxy and measuring its brightness in the sky the distance to the galaxy can be calculated.

The speed of distant galaxies can also be measured due to the red-shift of the light from the stars in the galaxy. Red-shift is the lengthening in the wavelength of lines in the spectrum of a distant star or galaxy. For relatively close by distant galaxies doppler red-shift is the dominant mechanism. For the most distant galaxies cosmological red-shift, caused by the expansion of the Universe is the dominant mechanism. Red-shift, $\mathbf{z = \Delta\lambda/\lambda = v/c}$ which can re rearranged to give $\mathbf{v = c\Delta\lambda/\lambda}$ the recessional velocity of the galaxy.

Hubble showed that the more distant a distant galaxy the faster it was moving away. A graph of distance against velocity is a straight line. The Hubble relationship is given by $\mathbf{v = H_0 d}$ where H_0, the Hubble constant is given by **v/d** where **v** is the recessional velocity of a distant galaxy and **d** is the distance to the distant galaxy.





This is consistent with an expanding universe. If the Universe is expanding then there are two likely explanations. Either the Universe started off very small (Big Bang) or as the Universe expands new material is created to fill the space (Steady State).

The Hubble constant, H_0 is a measure of the rate of expansion of the Universe. The best value for H_0 has changed significantly over the years, and continues to change, as more and more observations are made. It can be expressed in a number of different units.

Distance Unit	megaparsec, Mpc (3.1×10^{22}m)	light year (9.6×10^{15} m)	m
Velocity Unit	km/s	m/s	m/s
H_0 Unit	km/s / Mpc	m/s / light year	s^{-1} (m/s /m)
Value	70	0.022	2.2×10^{-18}

$1/H_0$ = distance/velocity = time so $1/H_0$ is the age of the Universe. $1/2 \times 10^{-18} = 4.5 \times 10^{17}$ s = **14×10^9 years**
This calculation might be wrong as the rate of expansion, H_0, might have changed. If the expansion was slower in the past the Universe might be older than we think. Galaxies were not formed at the beginning of the universe so can't tell us about the early expansion of the Universe. There is also some dispute as to the value of the Hubble constant – different approaches to measuring it yield different values. The Hubble constant is anything but!

For even more distant galaxies the red-shift in the wavelength of light received is dominated by **cosmological red-shift**. This is where the wavelength of light is stretched by the expanding space of the Universe during the time the light is travelling. The longer it travels the greater the expansion so the greater the red-shift. The expansion factor of the Universe is given by z + 1. If z = 10 then we are looking back to when the Universe was 1/11 its current size. **Expansion factor = z + 1 = ($\Delta\lambda/\lambda$) +1**

Cosmic Microwave Background, CMB

The cosmic microwave background is the oldest, most red-shifted light we can see. This is because it is the (thermal / black-body) light emitted when the Universe had expanded and cooled enough to first become transparent. This visible light emitted 380,000 years after the Big Bang has travelled through space and been cosmologically red-shifted by the expansion of the Universe by a factor of around 1000 into the microwave region of the electromagnetic spectrum. This red-shift of around z = 1000 results in the photons having an energy corresponding to around 3K, 1000 times lower than the 3000K when emitted. During the time it has been travelling the Universe has expanded by the same factor of 1000.

The CMB confirms the Big Bang explanation of Hubble's Law and rules out the Steady State interpretation. The CBM comes from all directions of space and is very, very uniform (same wavelengths and intensity) indicating that the early Universe was very smooth with uniform temperature to several significant figures.