Our Place in the Universe

Measuring Distances

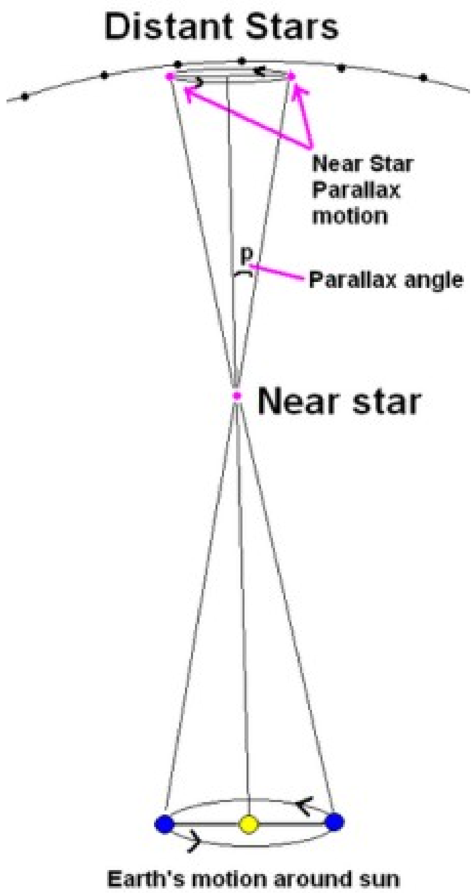
Radar Ranging – used for close objects such as asteroids (does not work for stars as they act as black bodies, absorbing the radiation).

Two separate radar signals are sent. If the signal takes longer to get back, the object is travelling away, and vice versa. The distance is simply found by:

$$Distance = \frac{Speed \times Time}{2}$$

The speed of the signal is known, the time is then measured. The distance will be found by dividing this by 2, as the time measured will be the time it takes there and back.

Parallax – used for close to medium distances (when too far, the angle is too small to be accurate, approx. 10^3 ly away). Simple trigonometry.



One Parsec (Pc) is when the angle of parallax is 1 arcsecond, i.e. 1/3600°. The distance is approximately 3.09×10^{16}m.

Standard Candles – Measure distance to distant objects.

e.g. Cepheid Variables (Henrietta Leavitt - pulse fluctuations $\propto$ distance [pule rate determined by size, bigger = slower pulsation], used for $10^3 – 10^7$ ly); Blue Giants; Type 1A Supernovae (assumption that these are constant intensity in any part of the universe, luminosity decreases as $1/r^2$, where r is distance).

These distances are measured by measuring the intensity (the rate of flow of energy per unit area at right angles to the direction of travel of the wave).

$$I = \frac{P}{(4\pi r^2)}$$

Where I is the intensity (Wm^{-2}), P is the Power (W) and r is the distance (m).

This is because if you have waves radiating evenly from a point source, then at a distance r from the source, the power is spread out over a sphere of surface area $4\pi r^2$. Notice that the intensity varies as an inverse square law of the distance.

e.g. 200W lamp, distance of face (at temperature which seems to be as hot as the sun) to the lamp = 0.7m.

Hence intensity of lamp at 0.7m = intensity of sun at 149×10^6.

$$I = \frac{(P_{lamp})}{(r^2_{lamp})} = \frac{(P_{sun})}{(r^2_{sun})}$$

Hence it is possible to work out either power or distance, depending on the information given.

Doppler Shift

This is where wave frequencies and lengths are shifted. e.g. An ambulance which has the same note, but as it moves towards you its siren sounds higher pitches (and past you it sounds lower), because the waves bunch together in front of the source and stretch out behind it. The amount of stretching or bunching depends on the velocity of the source.

When a light source moves away from us, the wavelengths of its light become longer and the frequencies become lower. This shifts the light towards the red end of the spectrum and is called redshift (remember this doesn't have to look red, it just means the wavelengths have increased). When a light source moves towards us, the opposite happens and the light undergoes blueshift.

To measure the distance of a star, we use the light it emits. We use the gas hydrogen (which constitutes stars), of which the wavelengths we know. The relative velocity of the Earth and a star will change the wavelengths of this emission of light.

$$z = \frac{(\Delta\lambda)}{\lambda} = \frac{v}{c}$$

Where z = doppler shift, $\Delta\lambda$ = change in wavelength, λ= original wavelength, v = velocity of object, c = velocity of light.

NB. This is only true for $v \ll c$, (otherwise relativistic formula needed!) and $z < 1$ (has to be in the same factor of 10).

The spectrum of hydrogen is used to find the velocity of the object (electron excitation, ground state, emitting a photon of f = E/h). If the same pattern is received, but it has all been shifted, the distance it has been shifted on the spectrum is Δλ, which is measurable.

Using doppler shift to find the mass of an object.

e.g. A star orbits a black hole, we can find the mass of the black hole.

As the star moves towards you, there is a blueshift. As it moves away, there is a redshift.

- We can measure the velocity of this star as it orbits.
- We can measure the time of orbit, i.e. time it takes to go from red to blueshift = ½ orbit time.

$$\frac{v^2}{r}=\frac{GM}{r^2} \quad \text{(because } a=\frac{v^2}{r}=g \text{ and } g=\frac{GM}{r^2}\text{)}$$

We need r, but v= s/t. Hence 2πr = vt (orbit is circular), therefore $r=\frac{vt}{(2\pi)}$

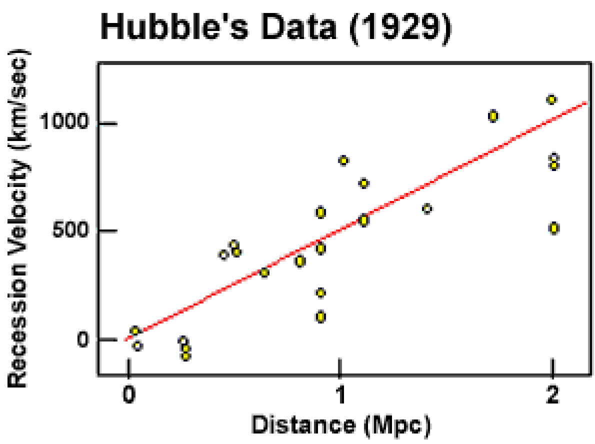
We can now find the "mass" of the black hole.

Problems:

- Only works when on the same plane as the orbiting object (else your red/blue shift measurements will be wrong).
- Orbits aren't circular
- Assumption of constant velocity.

The Big Bang

Edwin Hubble (1929) measured distances and recession velocities of galaxies. When he plotted the results, he found it was a straight line! The further away the objects are, the faster they move away.



y=mx, hence $m=\frac{(recession\, velocity)}{distance}$. This is known as the **Hubble Constant, H_0** (s^{-1}).

$$\frac{1}{H_0}$$ = Hubble Time (s), i.e. the age of the universe.

This is constantly revised, no one knows the exact value of H_0. Current best value = 14 billion years. (Age of solar system = 4.6 billion years).

The **singularity** is the "point" at which the big bang started. The big bang was a rapid expansion of space and time itself. There is no central point, the expansion is like that of a surface of a balloon. Inflation = FTL expansion.

Evidence for the Big Bang

Cosmic Microwave Background Radiation:

- CMB – accidentally detected by Penzias and Wilson in 1960s.
- The Big bang model predicts that a lot of electromagnetic radiation was produced in the very early universe. This radiation should still be observed today, and it is fairly evenly distributed.
- Because the universe has expanded, the wavelengths of the CMB have been stretched and are now in the microwave region (lots of shift, suggesting a long time ago).

In the late 1980s, a satellite called the Cosmic Background Explorer (COBE) was sent up to have a detailed look at the radiation.

It found a perfect black body spectrum, corresponding to a temperature of 2.73K. The radiation is isotropic (everything looks the same in every direction) and homogeneous (every part is the same as every other part), which confirms the Cosmological Principle (so it doesn't have a centre).

There are very tiny fluctuations in temperature, which are at the limit of detection. These are due to tiny energy-density variations in the early universe, and are needed for the initial 'seeding' of galaxy formation.

The background radiation also shows a Doppler Shift, indicating the Earth's motion through space. It turns out that the Milky Way is rushing towards an unknown mass (the Great Attractor) at over a million miles an hour.

The Amount of Helium in the Universe

The early universe had been very hot, so at some point it must have been hot enough for hydrogen fusion to happen. This meant that, together with the theory of the synthesis of the heavier elements in stars, the relative abundances of all of the elements could be accounted for.

Cosmological Redshift – Hubble's discovery of the further the distances, the faster the recession. Hence there must have been a point, back in time, where the objects were closer and closer = one point, the singularity, suggesting a Big Bang beginning.

Cosmological Redshift is the space itself expanding, i.e. redshift, $z \geq 1$.

$$\frac{R_o}{R_E} = \frac{\lambda_o}{\lambda_E}$$

Where R_o = radius of universe observed; R_E = radius of universe when light was emitted; λ = wavelength of light observed; λ = wavelength of light emitted.

$\lambda_o = \Delta\lambda + \lambda_E$ (wavelength observed = change in wavelength + emitted wavelength)

$$z = \frac{(\Delta\lambda)}{\lambda}$$

Therefore,

$$\frac{R_o}{R_E} = \frac{(\lambda_E + \Delta\lambda)}{\lambda_E}$$

Hence,

$$\frac{R_o}{R_E} = 1 + z$$, where z = doppler shift.