The Expanding Universe and Hubble's Law

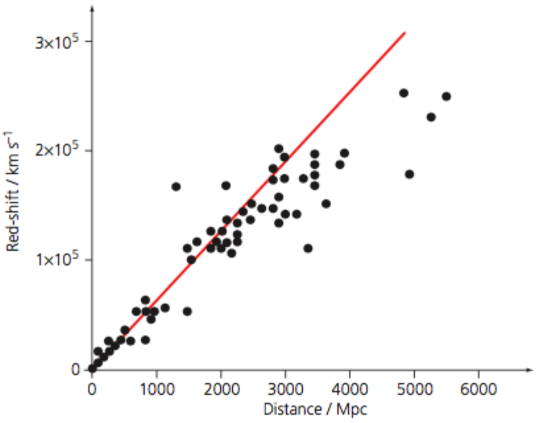
The Recession of Galaxies and Quasars

When light from whole galaxies is analysed, in the vast majority of cases, the absorption (or emission) spectra from distant galaxies is found to be red-shifted. This indicates that all of these galaxies are moving away from us and so is evidence of an expanding Universe. The red-shift is given by: $z = -\frac{V}{c}$

Where *v* is the galaxy's **recession velocity** relative to our own Galaxy, the Milky Way. Note that *z* is positive for a red-shift, since recession velocity is taken to be negative.

Hubble's Law

The spectra of all galaxies, apart from a few very near to our own Milky Way, show red-shift. A plot of the recession velocity against distance for galaxies is close to a straight line and is called a **Hubble diagram.** The data shows that the rate at which a galaxy recedes is directly proportional to its distance from us, that is, $v = Hd$.



v is the recession velocity in kms−1 and *d* is the distance of the galaxy in Mpc. This is called **Hubble's law** and the constant of proportionality *H* is the **Hubble constant**, which is the gradient of a Hubble diagram. Current best estimates give $H = 67.3 kms^{-1}Mpc^{-1}$. Note that the SI unit for *H* is s^{-1}. To get *H* in SI units, *v* has to be in ms^{-1} and *d* in m (1 Mpc = 3.09×10^{22} m).

Hubble's Law and the Big Bang

Hubble's law states that the Universe is expanding. An expanding Universe means that it is cooling down – so the further back in time, the smaller and hotter the Universe was. This implied to theoretical physicists that at a time *t*=0 the Universe came into being from an infinitely hot, infinitely dense point (called a singularity) and has been expanding ever since. This is the **Big Bang theory**, sometimes now called the Hot Big Bang (HBB) model.

An accurate value of the Hubble constant, allows an estimate of the age of the Universe. If in time *t* a galaxy has moved outwards a distance *d* at velocity *v*, then:

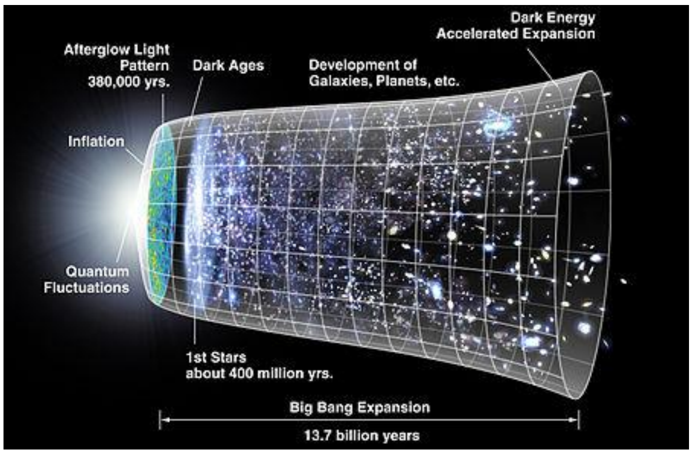
$t = \frac{v}{d}$ but from Hubble's law we have $v = Hd$ so, if we assume *H* has been constant, then

$time\ (age\ of\ universe = \frac{v}{d} = \frac{1}{H}$

Here *H* needs to have unit s^{-1}. Taking $H = 67.3 kms^{-1}Mpc^{-1}$, using 1 Mpc = 3.09×10^{22}m, we obtain $H = 2.18 \times 10^{-18} s^{-1}$

$H = 4.59 \times 10^{17}$ s = **<u>14.5 billion years</u>**

Rate of expansion of the Universe



Observations of distant galaxies has shown that they are less bright than predicted (calculated using Hubble's law). This shows that they are further from us than predicted by Hubble's law – the light from them has taken longer to reach us than predicted by a constant rate of expansion (H). This indicates that the rate of expansion is not steady, but is *accelerating*. Cosmologists were puzzled as to what could be driving this acceleration. The cause did not appear to be either matter or radiation, and is still at present unknown. Several possibilities have been put forward, including the notion of **dark energy**. This is a postulated energy that exerts an overall repulsive effect throughout the Universe, causing 'empty' space to expand, and its effect increases as the Universe expands.

While dark energy opposes the force of gravity, it adds to the total mass–energy density within the Universe. **Dark matter** emits no radiation, so is difficult to measure – its presence is inferred by the movement of galaxies. Current experimental data estimates that the Universe is composed of 27% matter and 73% dark matter, resulting in an ever-expanding Universe.