

The Expanding Universe and Hubble's Law

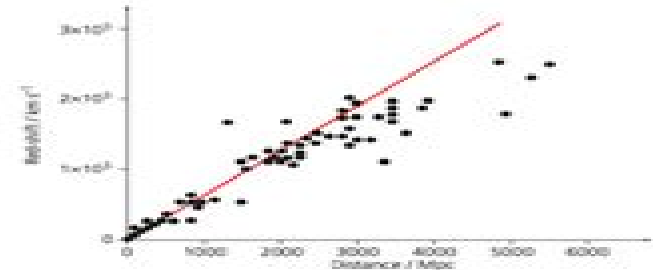
The Recession of Galaxies and Quasars

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 $H = 67.3 \text{ kms}^{-1} \text{ Mpc}^{-1}$. 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 ($1 \text{ Mpc} = 3.09 \times 10^{22} \text{ m}$).



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:

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

$$t = \frac{d}{Hd} = \frac{1}{H}$$

Therefore, the age of the Universe is the reciprocal of the Hubble constant. The Hubble constant is measured in s^{-1} so the age of the Universe is in seconds. The age of the Universe is approximately 14 billion years .

Expansion of the Universe

The expansion of the Universe is the increase in the scale factor of the Universe over time. The scale factor is a measure of the size of the Universe. The expansion of the Universe is described by the Friedmann equations. The first Friedmann equation relates the expansion rate of the Universe to the energy density of the Universe. The second Friedmann equation relates the acceleration of the expansion to the pressure of the Universe. The expansion of the Universe is a key prediction of the Big Bang theory.

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