The Hubble Expansion

During the 1920's and 30's, Edwin Hubble discovered that the Universe is expanding, with galaxies moving away from each other at a velocity given by an expression known as Hubble's Law:

\[ v = H \times r \]

with
- \( v \) represents the galaxy's recessional velocity,
- \( r \) is its distance away from Earth, and
- \( H \) is a constant of proportionality called Hubble's constant.

The exact value of the Hubble constant is somewhat uncertain, but is generally believed to be around 70 kilometers per second for every megaparsec in distance, km/sec/Mpc. (see e.g. the online proceedings of How Far Can You Go?. A megaparsec is given by 1 Mpc = 3 x 10^6 light-years). This means that a galaxy 1 megaparsec away will be moving away from us at a speed of about 70 km/sec, while another galaxy 100 megaparsecs away will be receding at 100 times this speed. So essentially, the Hubble constant sets the rate at which the Universe is expanding.

Additionally, the present age of the Universe can be assessed vis-a-vis the Hubble constant: the inverse of the Hubble constant has units of time. By substituting in kilometers for Mpc in the Hubble constant, we find that upon inverting \( H \) we get a quantity with units of seconds (kilometers canceling out in the denominator and numerator). For a Hubble constant of 100 kilometers per second per Mpc, we get 3 x 10^17 seconds, or about 10 billion years.

The standard picture of cosmology, based on Einstein's general theory of relativity explains how to picture this expanding universe. As an example consider a loaf of bread, with raisins sprinkled evenly throughout it. As the bread expands during
cooking all the raisins are moved further and further apart from each other. Seen from any raisin all the other raisins in the bread appear to be receding with some velocity.

This model also explains the linearity of the Hubble law, by which we mean the fact that the recession velocity is proportional to distance. If all the lengths in the universe double in 10 million years then something that was initially 1 megaparsec away from us will end up a further megaparsec away. Something that was 2 megaparsecs away from us will end up a further 2 megaparsecs away. In terms of the speed at which the objects appear to be receding from us, the object twice as distant has receded twice as fast!

On very large scales Einstein's theory predicts departures from a strictly linear Hubble law. The amount of departure, and the type, depends on the amount and types of mass and energy of the universe. In this way a plot of recession velocity (or redshift) vs. distance (a Hubble plot), which is a straight line at small distances, can tell us about the amount of matter in the universe and provide crucial information about dark matter.

For more information on one promising way to measure the departures from the linear Hubble law and measure the mass density of the universe, see the Home Pages of the Supernovae Cosmology Project and the High Z Supernova Team. These teams were the first to report evidence, from the type of plot above, that the expansion of the universe today is being dominated not by matter but by dark energy, causing distant supernovae to appear fainter than they would in a purely matter dominated universe. Recent work at very high redshift has begun to detect the transition to a matter dominated universe, during which time the expansion of the universe decelerated.

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