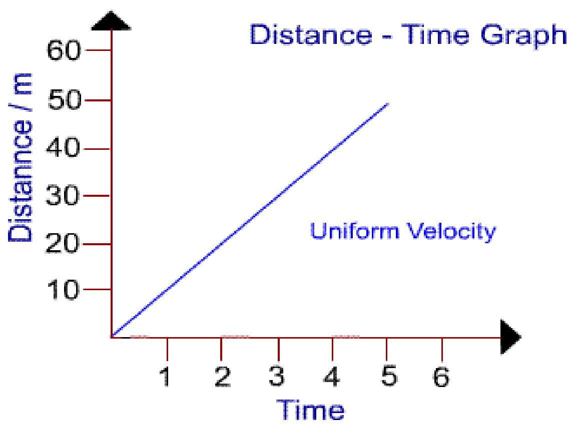
Hubble's observation was that in different galaxies, the wavelength of light was different:
He did this by looking at the spectral lines of galaxies

Relative to our sun, all remote galaxies are red-shifted, which means that the wavelength of light is longer.

This led to Hubble's Law: the greater the distance to a galaxy, the greater its redshift. We can use this relationship to tell us the age of the universe!

Imagine you are driving in your car at a uniform speed. You use a stopwatch and keep an eye on the mileage meter in your car. As you drive, you record your observations, and make a plot that looks like this:



Your speed stays the same, so you know that velocity will be a straight line.

This is the relationship: $velocity = \frac{distance}{time}$

And another benefit is that you can figure out when you started…

All stars are made up on similar elements, and they have characteristic lines associated with different elements in them. The different between the energy in the lab measurements (λ_0) and the energy of the band you measure in your galaxy (λ) actually can tell us how fast the star is moving…

$$z = \text{redshift} = \frac{\lambda - \lambda_0}{\lambda_0}$$

So, for example, if the "true" position of Ca in the lab is λ_0=393.3 nm and the same line appears in a distant star at 401.8 nm, then z=$\frac{401.8nm - 393.3nm}{393.3nm}$, or 0.0216.

$$z = \frac{velocity}{c = speed\ of\ light}$$

So v = cz

The speed of light = 299,792,458 m/s or **3x10^5 km/s**

So that star is moving at a speed of v = (3x10^5 km/s) x 0.0216 = 6480 km/s!

Now, how do we know the age of the universe?

Let's begin with the familiar relationship used on the speedometer of our car:

We have the relationship: $velocity = \frac{distance}{time}$

but we want to know TIME.

So we convert it to: $time \times velocity = \frac{distance}{time} \times \frac{time}{1}$

And: $time \times velocity = distance$

Or $time = \frac{distance}{velocity}$ (often expressed as $T_0 = \frac{d}{v}$)

So if we know distance and velocity, we can figure out how old the universe is!

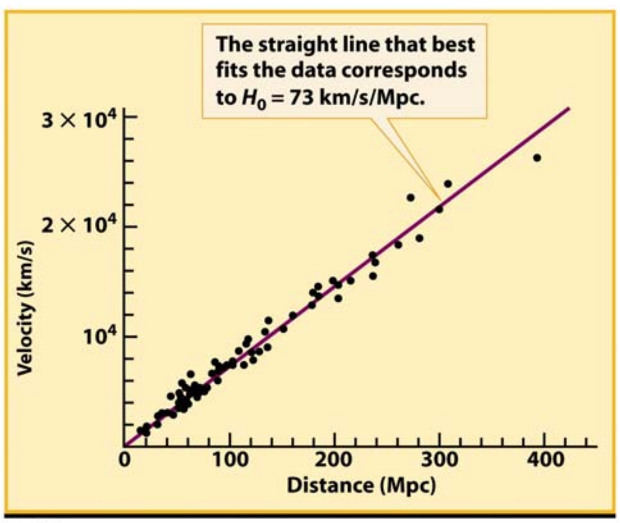


Figure 24-17
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NOW Let's look at Hubble's constant

Edwin Hubble in the 1920s found that all far away objects (such as other galaxies) in the universe are moving away from us, and that this motion, called their recession velocity, is greater the further they are from us. In fact, he found the relationship between a galaxy's velocity (the radial component, in a straight line) away from us (*v*) and its distance from us (*d*) approaches a fairly linear one, which is known as Hubble's Law:

$$v = H_0 \text{ x } d$$

So if we plot the velocity of many stars vs. distance (as shown above), the slope of that line is H_0, or the Hubble Constant. It's about 73 73 km/s/Mpc.

Notice that this line is plotted with velocity (of each galaxy) on the *y* axis and distance (away from us, usually expressed in Mpc, or megaparsecs) on the *x* axis, because H_0 is formally defined as *v*/*d*. That's because it happens to be the way Hubble formulated it. But the same principle applies: we use the slope to determine time.

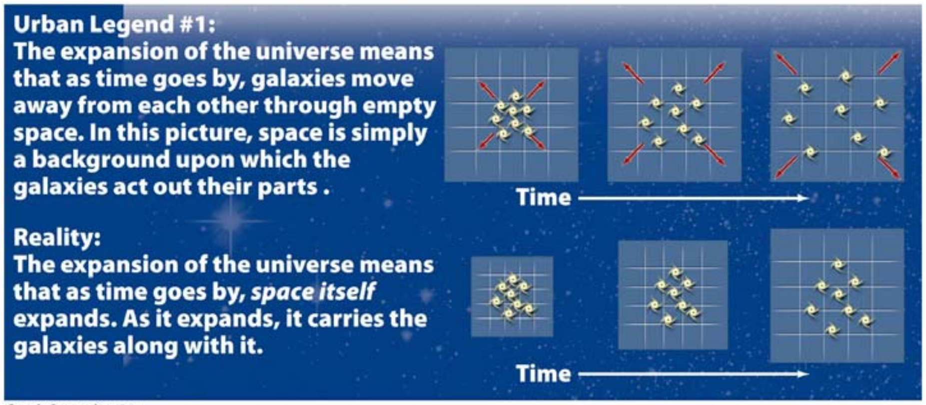
How do we use this graph to tell us the age of the unjiverse? Because we know that the slope of the line in the plot is 73 km/s/Mpc, we can simply write:

$$T_0 = \frac{1 Mpcs}{73 km} \times \frac{3.09 \times 10^{19} km}{1 Mpc} \times \frac{1 year}{3.156 \times 10^7 s} = 1.34 \times 10^{10}\, years = 13.4\, billion\, years$$

So now, we know how old the universe is!

The point is that all galaxies are moving away from us, at varying speeds proportional to distance. Thus, the universe must be expanding!

NOTE: expansion is primarily BETWEEN galaxies:



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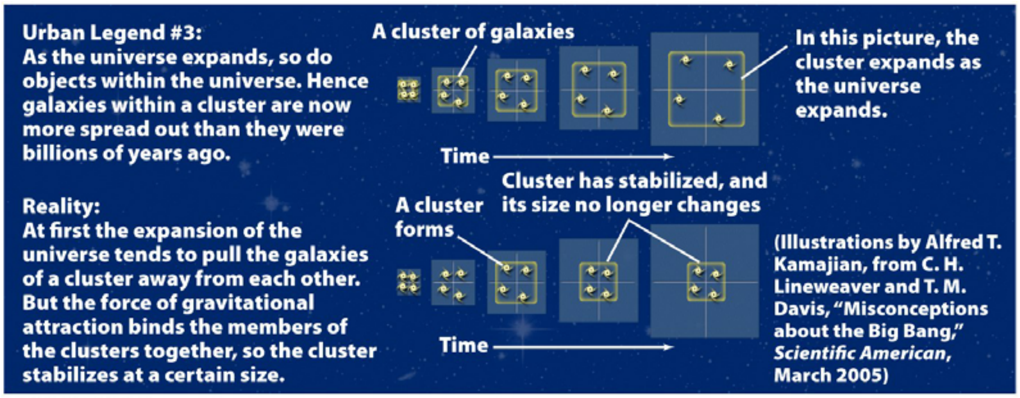

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The cosmological principle tells us that over very large distances, the universe is homogeneous (every region is the same as every other region) and isotropic (looks the same in every direction).