Geochemistry

Notes IV: Origin of the Universe

I. Light and wavelengths of light
II. The Doppler Effect, light from far away galaxies, and velocity
III. Cepheid Variables and distance
IV. The Big Bang

Light travels in waves. The parameters that change in a periodic fashion as light propagates are the electric and magnetic fields. Thus, light is a form of electromagnetic radiation. We perceive different wavelengths of light as different colors of light. Visible light has wavelengths ranging from 400 (violet light) to 700 (red light) nm. Electromagnetic radiation from the sun has a range of wavelengths essentially including all visible wavelengths as well as ultraviolet (UV) radiation and infrared (IR) radiation.

The Doppler Effect is the apparent shift in the wavelength as perceived by an observer moving relative to the source of a wave. If the observer and source are getting closer to each other, the perceived wavelength is shorter than the true wavelength. If the observer and source are getting further away from each other, the perceived wavelength is longer than the true wavelength. The component of relative velocity in the direction toward or away from the source can be calculated: $\lambda'/\lambda = 1 + v/c$ (see Chapter 2), where λ' is the perceived wavelength, λ is the true wavelength, v is the component of velocity described above and c is the velocity of light in a vacuum.

As it turns out, for light from stars from far away galaxies, we know all of the variables in the above equation except for v, so we can calculate the component of velocity in question for any galaxies we can see with a telescope.

Electromagnetic radiation from stars has a range of wavelengths covering essentially the whole range of visible light range and beyond. However, in detail, some wavelengths are missing. These missing wavelengths are called Fraunhofer Lines, and result from the absorption of discreet wavelengths of light by the electron clouds of the various elements in the outer atmosphere of stars. Each line can be attributed to a specific energy difference in the electron cloud of a particular element. The intensity of these lines reflects the concentration of the element in question in the atmosphere of the star. The pattern of Fraunhofer Lines in the sun is known very well. In light from far away galaxies, the Fraunhofer Lines are shifted (see figure).

If we pick one line, we know its true wavelength from the sun (which is not moving toward or away from us) or laboratory experiments. If we look at the same line in light from a star in a far away galaxy (that is moving relative to us), we know its perceived wavelength. We know the speed of light, and can therefore calculate the rate at which that galaxy is moving toward or away from us. We can do this calculation for different lines from the same galaxy and get the same answer. We can also do this calculation for different galaxies. When we do this we find that all galaxies are moving away from us - we perceive light from these galaxies as longer in wavelength than the true wavelength. We refer to this light as "Red Shifted" because red light is the longest wavelength of visible light. This means that all of these galaxies are moving away from us, but at different velocities.

We can also calculate the distance to different galaxies. This calculation uses the principle that luminous objects that are far away appear dimmer (apparent luminosity) than those that are nearby. To calculate the actual distance on the basis of apparent luminosity of an object, you need to know the object's absolute luminosity (the actual brightness of the object). This is known for a set of stars called Cepheid Variables, which pulse at a rate that is related to their average absolute luminosity (as determined by Henrietta Levitt at the beginning of the 20th Century). From the pulse rate of these stars and their average apparent luminosity, we can calculate distance.

By dividing distance by velocity for each galaxy, we can determine the time since each galaxy was close to us. As it turns out, this time is the same for all galaxies, about 15 billion years. This line of reasoning is the basis for the Big Bang Theory of the origin of the Universe.