Observational Astronomy - Spring 2014
Homework 11 - Cosmology 2

1. Figure 1 on the next page shows a photograph of a Type-1A supernova which occurred in the galaxy NGC 3370 in 1994. Figure 2 shows the light curve of this supernova, showing how the brightness varied with time. By comparing the rate of decline of this light curve with other measured supernovae of this type, we can see (the "+" sign in Figure 3) that a supernova of this type has a peak intrinsic brightness given by an absolute magnitude M = -19.0. Using this and the measured apparent magnitude from Figure 1, calculate:

   (a) The distance to the galaxy NGC 3370.

   - The peak absolute magnitude is -19.0 and the peak apparent magnitude is +13.1. From these, we can calculate the distance using:

$$\mathrm{m} = \mathrm{M} - 5 + 5\log_{10}(\mathrm{D})$$
$$13.1 = -19.0 - 5 + 5\log_{10}(\mathrm{D})$$
$$\log_{10}(\mathrm{D}) = \frac{37.1}{5.0} = 7.42$$
$$\mathrm{D} = 10^{7.42} = 26.3\,\mathrm{Mpc}$$

   - Other measurements of the distance to this galaxy range from 18.9 to 27.7 Mpc.

   (b) The speed at which NGC 3370 is moving away from us, assuming a Hubble constant of 70 km/sec/Mpc.

   - The speed of recession is just the distance times the Hubble constant:

$$\mathrm{D}_{10} = 26.3\,\mathrm{Mpc} \times 70\frac{\mathrm{km}}{\mathrm{sec\,Mpc}} = 1841\,\mathrm{km/sec}$$

   (c) The redshift z of NGC 3370.

   - The redshift is fairly small, so it is just given

$$\mathrm{z} = \frac{\mathrm{v}}{\mathrm{c}} = \frac{1841\,\mathrm{km/sec}}{300,000\,\mathrm{km/sec}} = 0.0061$$

2. The Cosmic Microwave Background (CMB) is radiation emitted when the universe cooled sufficiently that it became transparent. The radiation is measured today to be a nearly perfect blackbody with a temperature T of 2.74° K, meaning that it is just 2.74° above absolute zero. Answer the following questions about the CMB:

   (a) Using the relation that you learned in lab that the peak wavelength of a blackbody of temperature T is given by $\lambda_{\mathrm{peak}} \times \mathrm{T} = 3.0\,\mathrm{mm\,K}$, calculate the peak wavelength of the CMB.

   - Substituting T = 2.74 K into the equation gives:

$$\lambda_{\mathrm{peak}} = \frac{3.0\mathrm{mm\,K}}{2.74\mathrm{K}} = 1.09\,\mathrm{mm}$$

(b) In what region of the electromagnetic spectrum is this wavelength?

- This is in the microwave region of the EM spectrum (hence the name). Microwaves are short wavelength radio waves.

(c) The CMB has been redshifted by about a factor of 1000 since it was emitted, so it is at z=1000. Using the relation:

$$z = \frac{\lambda_{observed} - \lambda_{emitted}}{\lambda_{emitted}},$$

calculate the peak wavelength at which the CMB was emitted.

- Solving for λ_e :

$$\mathrm{z} = \frac{\lambda_\mathrm{o} - \lambda_\mathrm{e}}{\lambda_\mathrm{e}}$$

$$\mathrm{z}\lambda_\mathrm{e} = \lambda_\mathrm{o} - \lambda_\mathrm{e}$$

$$(1+\mathrm{z})\lambda_\mathrm{e} = \lambda_\mathrm{o}$$

$$\lambda_\mathrm{e} = \frac{\lambda_\mathrm{o}}{1+\mathrm{z}} = \frac{\lambda_\mathrm{o}}{1001} = \frac{1.09\,\mathrm{mm}}{1001} = 1.09\,\mu\mathrm{m}$$

(d) In what region of the electromagnetic spectrum is this wavelength?

- This is in the infrared region of the EM spectrum.

(e) At what temperature was the CMB emitted?

- Substituting λ_peak into the equation gives:

$$\mathrm{T} = \lambda_\mathrm{peak} = \frac{3.0 \times 10^{-3}\,\mathrm{m\,K}}{1.09 \times 10^{-6}\,\mathrm{m}} = 2742\,\mathrm{K}$$

(f) In what direction is the CMB? In other words, where do astronomers need to point their microwave detectors to detect the CMB radiation?

- The CMB radiation fills the universe, so we see it in all directions, no matter which direction we point the detector.