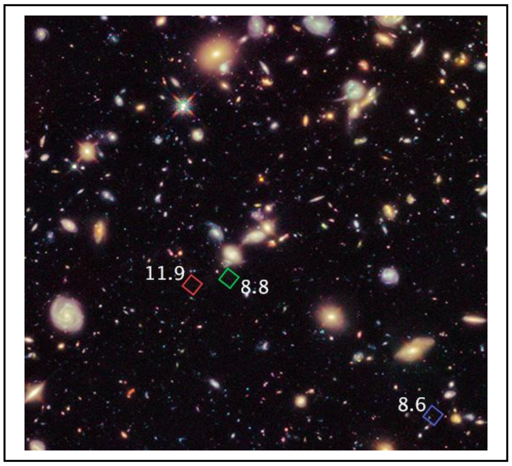
Exploring the Infant Universe



The Big Bang occurred 13.77 billion years ago. For the first million years after the Big Bang, the temperature was so hot that atoms could not form. It took another 50 to 100 million years before matter was cool enough to clump together to form small galaxies and the first generations of stars. Astronomers can look out into space and study the images of these infant galaxies, which appear as the most distant objects that their telescopes can discern. This photo was taken by the Hubble Space Telescope and shows some of these distant, faint galaxies.

Problem 1 – The most directly observable property of any object in the universe is its cosmological redshift, denoted by 'z'. As the universe expands, galaxies move away from each other at a speed V = 300,000 z, where V is its speed away from the Milky Way in kilometers/sec. Complete the table below to find the recession speeds or redshifts of the indicated galaxies.

	NGC-7317	3C273	OJ-287	4C-31.3	Mk-992	3C-265
Z		0.158		0.462	0.654	
V	6,600		91,800			243,300

Problem 2 – As the universe expands, the separation between two galaxies increases by a factor equal to (1 + z). Galaxies that we see at a redshift of z and separated by 1 million light years are now (1+z) million light years apart today. Suppose that the Milky Way and the Andromeda Galaxies were once just touching each other and only 50,000 light years apart. Write a linear equation that predicts the separation between these galaxies if they were observed at a redshift of z. If the separation is now 2,200,000 light years, at what redshift were they just touching each other?

Problem 3 - As the universe expands, the matter and energy in space steadily cools over time. The temperature of the universe in Celsius is given by the exact formula $T = 2.72(1+z) - 273$. A) What is the temperature of the universe for objects seen at a redshift of z=100? B) At what redshift will the temperature of the universe equal the surface temperature of our sun, which is $5{,}500^{o}$ C?

Because light takes time to travel through space, when we look at a distant galaxy, we are seeing it as it was long ago. Big Bang theory predicts the exact formula that relates the look-back time, T to the redshift, z. Although the function T(z) is non-linear, it can be approximated by the linear formula **T = 12505 + 81.2z** over the redshift range from $5.0 < z < 15.0$, where T is in millions of years.

Problem 4 – A very distant galaxy was discovered in 2012 called UDFj- 39546284 with z = 11.9. A) How long has light been traveling to get to Earth from this galaxy? B) If the universe is 13.77 billion years old, expressed in millions of years, how soon after the Big Bang did the light from this galaxy begin its journey?

Answer Key

Problem 1 – The most directly observable property of any object in the universe is its cosmological redshift, denoted by 'z'. As the universe expands, galaxies move away from each other at a speed V = 300,000 z, where V is its speed away from the Milky Way in kilometers/sec. Complete the table below to find the recession speeds or redshifts of the indicated galaxies.

	NGC-7317	3C273	OJ-287	4C-31.3	Mk-992	3C-265
Z	**0.02**	0.158	**0.306**	0.462	0.654	**0.811**
V	6,600	**47,400**	91,800	**138,600**	**196,200**	243,300

Problem 2 – As the universe expands, the separation between two galaxies increases by a factor equal to (1 + z). Galaxies that we see at a redshift of z and separated by 1 million light years are now (1+z) million light years apart today. Suppose that the Milky Way and the Andromeda Galaxies were once just touching each other and only 50,000 light years apart. Write a linear equation that predicts the separation between these galaxies if they were observed at a redshift of z. If the separation is now 2,200,000 light years, at what redshift were they just touching each other?

Answer: **S = 50000(1+z) light years**. For s = 2,200,000 light years today, we have 2,200,000 = 50000 (1+z) and solving for z we get **z = 43**.

Problem 3 - As the universe expands, the matter and energy in space steadily cools over time. The temperature of the universe in Celsius is given by the exact formula T = 2.72(1+z) - 273. A) What is the temperature of the universe for objects seen at a redshift of z=100? B) At what redshift will the temperature of the universe equal the surface temperature of our sun, which is 5,500 C?

Answer: A) T = 2.72(100+1) - 273, so T = 275 - 273 and so **T = 2^{o} C**.
B) 5,500 = 2.72 (1+z) – 273, so **z = 2121**.

Because light takes time to travel through space, when we look at a distant galaxy, we are seeing it as it was long ago. Big Bang theory predicts the exact formula that relates the look-back time, T to the redshift, z. Although the function T(z) is non-linear, it can be approximated by the linear formula T = 12505 + 81.2z over the redshift range from 5.0 < z < 15.0, where T is in millions of years.

Problem 4 – A very distant galaxy was discovered in 2012 called UDFj- 39546284 with z = 11.9. A) How long has light been traveling to get to Earth from this galaxy? B) If the universe is 13.77 billion years old, expressed in millions of years, how soon after the Big Bang did the light from this galaxy begin its journey?

Answer: A) T = 12505 + 81.2(11.9) = 13471 million years or **13.47 billion years**.
B) 13770 – 13471 = **299 million years after the Big Bang**. Note: This means we are seeing the galaxy as it was when the universe was only 299 million years old. The galaxy itself is younger than this because it formed after the Big Bang.