**What is Redshift?**

Astronomers use the term “redshift” to mean not only the apparent velocity of a galaxy moving away from us, but also to mean the galaxy’s distance from us and even its look-back time or age since the Big Bang. Distances and ages of galaxies are functions of galaxies’ apparent velocities, but the values of the distance and age depend on a cosmological model that depends in turn on several parameters, including the Hubble constant of the Universe today and the value of the Hubble constant as a function of time, as well as the density of the Universe as a function of time. Remember that the observed recession speed is due to the expansion of space itself, rather than the motion of the galaxies themselves.

For nearby galaxies with relatively small apparent recession velocities (say, less than about 30,000 km/sec, or 1/10 the speed of light), redshift is defined simply as the ratio of the apparent velocity divided by the speed of light:

$$z=\frac{v}{c}$$

Where *v* is the apparent recession velocity and c is the speed of light (300,000 km/sec). Objects with zero redshift are in our local universe, and increasingly distant objects have larger and larger redshifts.

For apparent recession velocities faster than about 30,000 km/sec (z=0.1), Einstein’s theory of special relativity must be taken into account. In this case, the formula for the redshift z becomes more complicated.

$$z=\sqrt{\frac{(1+\frac{v}{c})}{(1-\frac{v}{c})}}-1$$

As distance increases, recession velocity v approaches the speed of light, and the redshift z becomes larger and larger. The highest redshift objects yet observed are seen through gravitational lenses, which amplify their brightness. The objects have redshifts between 11 and 12 corresponding to recession velocities of more than 95% of the speed of light. The light we see from these sources was emitted just a few hundred million years after the Big Bang. The highest redshift objects we can image directly (without the benefit of a gravitational lens) have redshifts of 9-10, from objects roughly 700 million years after the Big Bang.

In the table on the next page, calculate the redshifts corresponding to each of the objects listed, using the redshift calculator at [**www.calctool.org/CALC/phys.relativity/redshift**](http://www.calctool.org/CALC/phys.relativity/redshift).

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| --- | --- | --- | --- | --- | --- |
| **Object** | **Type** **of** **Object** | **Apparent** **Velocity** **(km/sec)** | **Redshift****(z)** | **Age of the Universe** | **Look-back Time** |
| UDFj-39546284 | Protogalaxy | 296,200 |  |  |  |
| MACS J1149-JD | Protogalaxy | 294,500 |  |  |  |
| A1703 zD6 | Protogalaxy | 290,700 |  |  |  |
| HDF 4-473.0 | Galaxy | 286,500 |  |  |  |
| PKS 0237-23 | Quasar | 247,200 |  |  |  |
| SN SCP-0401 | SN Type Ia | 228,000 |  |  |  |
| 3C 295 | Radio Galaxy | 108,500 |  |  |  |
| NGC 4860 | Galaxy | 7,800 |  |  |  |

Next, use the Cosmology Calculator at [**www.kempner.net/cosmic.php**](http://www.kempner.net/cosmic.php) to find the age of the universe at the time the light we see was emitted at the source galaxy, and the lookback time to each object (how far back in time the object appears). The calculation of the age of the object and the lookback time depend on the specific cosmological model used. For our calculations, use the most recent values from the Planck mission announced two weeks ago

H0 = 67.8 km/sec/Mpc m=0.308 = 0.692

H0 is the current-day expansion rate of the universe

m is the fraction of the content of the universe that is in the form of matter (luminous+dark)

 is the fraction of the content of the universe that is in the form of “dark energy.”

In the chart below, plot the age at which each galaxy is observed versus redshift. The dashed curve is calculated for the specific parameters of the Planck model. How closely do the objects match the curve calculated for the Planck universe values?

For which object(s) in the table did the Earth and Sun exist when the light began its journey toward us?