Cosmological Distance

What do we mean by distance? Contrary to our everyday experience, our universe is so large that the concept of distance is complex and depends upon such things as the geometry of the universe, cosmic expansion, the speed of light, and other factors.

One way to define distance is to calculate the recession velocity of an object from its cosmological redshift, then convert that recession velocity to a lookback time using the Hubble Constant.

For an object receding from us, the redshift *z* is a positive number and is given by

$$z = \frac{\lambda_0 - \lambda_e}{\lambda_e} = \frac{\lambda_0}{\lambda_e} - 1$$

where	z	=	the redshift (or blueshift if negative), a unitless number
and	λ_0	=	the observed wavelength of a spectral line
and	λ_e	=	the emitted wavelength of a spectral line

Assuming that the kinematic redshift and gravitational redshift contribute negligibly to the total redshift (in other words, the entire redshift is cosmological, due to the expansion of the universe), which is not always the case (!), we can calculate the recession velocity as follows:

$$\frac{v}{c} = \frac{(z+1)^2 - 1}{(z+1)^2 + 1}$$

where	v	=	the recession velocity (in km/s)
and	c	=	the speed of light, *exactly* 299792.458 km/s

Then, to get the distance in "megaparsecs" (Mpc), use the Hubble relation

$$v = H_0 D$$

where	v	=	the recession velocity in km/s
and	H_0	=	the Hubble Constant, 70.1 ± 1.3 km/s/Mpc
and	D	=	the distance in Mpc

Combining these equations and knowing that 1 Mpc = 3.26163626 Mly, we get

$$D = 13949 \left[\frac{(z+1)^2 - 1}{(z+1)^2 + 1} \right]$$

where	D	=	the distance in megalightyears (Mly)

While this formulation works well for most galaxies, quasars, etc., it becomes significantly inaccurate for extremely distant objects.

Now, how far away are the brightest quasar 3C 273 in Virgo (z = + 0.15834, from *SIMBAD*), and distant supernova hSDF0503.40 at z = +1.564?

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