

Accelerating Expansion of the Universe: Yes or No?

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1 Introduction

Over the past decade most cosmologists have come to believe that the universe is expanding at an accelerating rate. Seeming evidence for this acceleration has been provided by brightness measurements of many newly discovered type Ia Supernovae. These supernovae were discovered to be unexpectedly faint for the distance at which they were according to standard cosmology. If their distances were indeed correct, the unexpected faintness of the supernovae would indicate that the universe is larger than thought. This could be explained by postulating an accelerating expansion, which is the way standard cosmology explains it. Another theory, the Dynamic Universe (DU) theory explains the same measurements just as well as standard cosmology, but without the need for the expansion of the universe to be accelerating. In this essay I will describe both approaches.

In this essay I'll be using several terms such as "magnitude", "distance", "flux", "redshift", and "distance modulus". These terms will be introduced as we go along. In cosmology, brightness measurements of stellar objects – stars, galaxies, supernovae, etc. – are normally converted to "magnitudes". The magnitude scale was devised by the ancient Greeks to describe the perceived brightness of stars. They assigned the brightest stars a magnitude of 1, and the faintest a magnitude of 6. The magnitudes we use today are based on that same scale, but we use mathematical equations to convert an object's brightness – its "wattage" which we can measure objectively and accurately – to its magnitude. There are two such equations that will be used in this essay. There is no controversy about these equations; they are direct consequences of the mathematical definition of magnitude. Standard cosmology computes magnitudes based on an object's distance from earth:

$$m = M + 5 \log_{10} d_L + 25 \quad (1)$$

In this equation, M is a reference magnitude whose value in the case of type Ia supernovae (which are the only stellar objects I'll be talking about) is approximately -19.31. ' m ' is an object's magnitude in relation to M . ' d_L ' is luminosity distance the distance from earth to the object in megaparsecs (more about luminosity distance later). Actually, cosmologists find it more convenient to use the equivalent equation:

$$m - M = 5 \log_{10} d_L + 25 \quad (2)$$

Cosmologists call the term " $m - M$ " the "distance modulus" and give it the name μ . So we have:

$$\mu = m - M = 5 \log_{10} d_L + 25 \quad (3)$$

Cosmologists call $\mu = m - M$ the “distance modulus” because its principal use is as a measure of distance to stellar objects. However, since M for type Ia supernovae is a constant (about -19.31), μ can be used as a measure of a type Ia supernova’s magnitude or brightness. And that is how it will be used in this essay.

The Dynamic Universe (DU) theory uses a much different approach. It computes magnitudes based on an object’s observed “flux” as measured on earth:

$$m = -2.5 \log_{10} (F_{obs} / F_r) \quad (4)$$

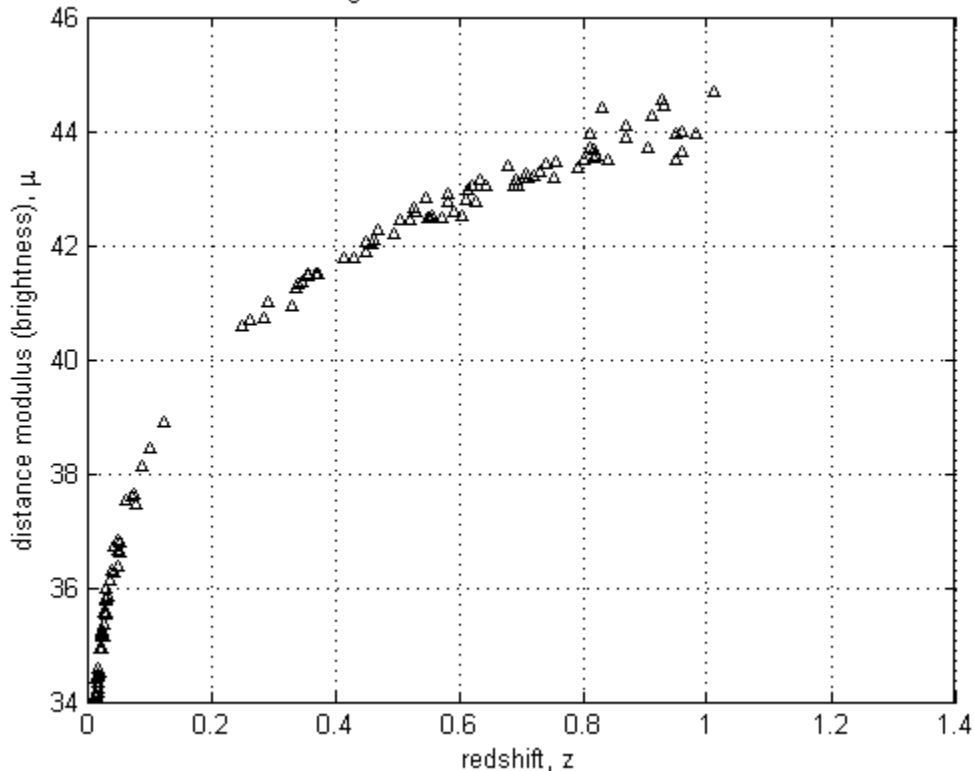
The observed flux, F_{obs} , is a measure of the brightness of illumination over a square meter. F_r is a reference flux whose value is approximately 2.53×10^{-8} watts per square meter. As I will show later in this essay, the DU equation can easily be expressed in terms of the distance modulus μ , so that both models will use the same independent variable, which will be the vertical scale in the figures.

The dependent variable that will be used for both models (the horizontal scale in the figures) is “redshift”. Redshift is the customary variable cosmologists use in plots of cosmological measurements that are dependent on distance. For comparing the standard cosmology and the DU models of type Ia supernova data, redshift is especially convenient because distance in standard cosmology and the observed flux in the DU can both be expressed in terms of redshift. Briefly, redshift, denoted by z , is the fraction by which the wavelength of light an object emits has increased while it has traveled from the object to earth. The wavelength increases because as the light travels, its wavelength increases along with the expansion of the universe.

2 The Data

The data is where “the rubber meets the road”. Figure 1 shows a plot of what is probably the best data that has so far been obtained from measurements of type Ia supernovae.

Figure 1. The data we want to fit.



The data plotted in Figure 1 was published in 2005 by a group of researchers led by Pierre Astier of the Centre National de la Recherche Scientifique in France. You can find it at http://arxiv.org/PS_cache/astro-ph/pdf/0510/0510447.pdf. The plot shows the distance modulus of 115 type Ia supernovae plotted against their measured redshift. What we would like to do is find models, i.e. equations, that fit this data. The data, having been obtained by real-world measurements, is “shaky” – it contains random fluctuations. Our goal is to find an equation for a smooth curve that goes as close as possible to all of the points and has the same overall shape as the data. The better the curve, the more confidence we can have in the model that produced it. In the following sections, I’ll describe the curve that results from standard cosmology and the curve that results from the DU.

3 Standard Cosmology: the Expansion of the Universe is Accelerating

As stated earlier, standard cosmology uses the equation $\mu = 5 \log_{10} d_L + 25$ to relate distance to distance modulus. Since we want to use redshift as the dependent (horizontal axis) variable, we need to relate the distance, d_L , to redshift, z . In standard cosmology this relationship is very complex, but it takes into account how standard cosmology models the shape and expansion of the universe. Here’s the equation:

$$d_L = \frac{c(1+z)}{H_0} \int_0^z \frac{1}{\sqrt{(1+z)^2 (1+\Omega_m z) - z(2+z)\Omega_\lambda}} dz \quad (5)$$

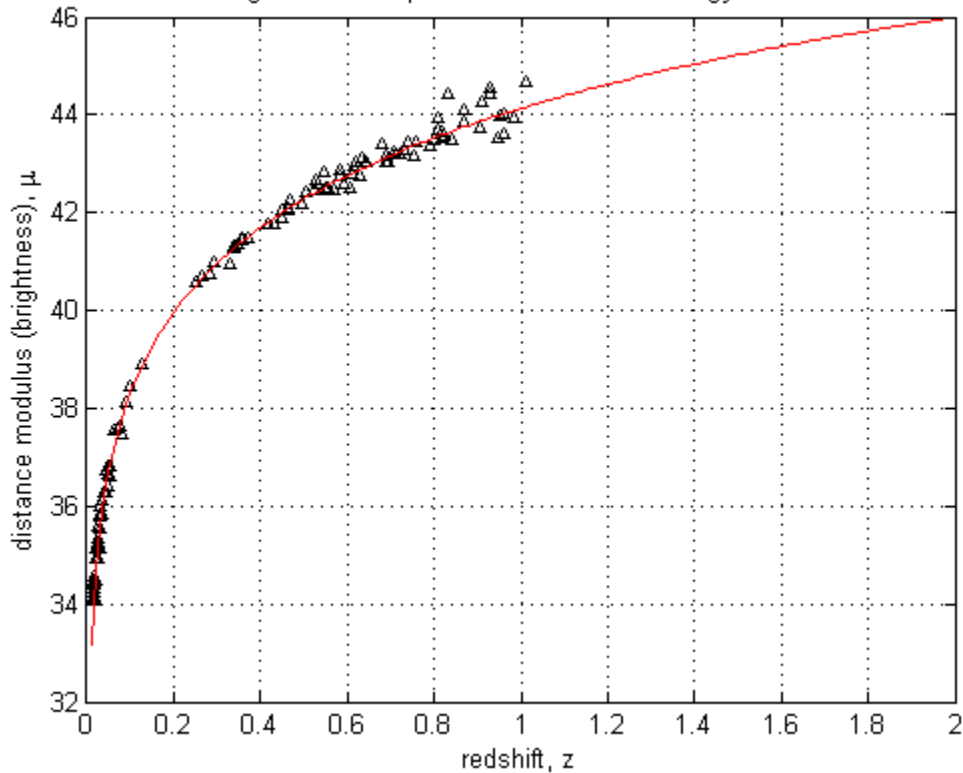
For a derivation of this equation, see: S. E. Carroll, W. H. Press, and E. L. Turner, 1992. "The Cosmological Constant," *Ann. Rev. Astron. Astrophys.*, 30, 499. Here's a link to the article:

http://adsbit.harvard.edu/cgi-bin/nph-article_query?bibcode=1992ARA%26A..30..499C

In this equation, 'c' is the speed of light and H_0 is the Hubble constant (which represents the expansion rate of the universe), and both have fixed values ($c = 299792$ km/sec, and $H_0 = 70$ km/sec/megaparsec). That leaves us with two parameters to play with, Ω_m and Ω_λ . These are "density" parameters. Ω_m is the matter density of the universe and Ω_λ is the "dark energy" density. Dark energy, according to standard cosmology, is an unseen repulsive force that pervades the universe. Enough of it would cause the expansion of the universe to accelerate. The values of Ω_m and Ω_λ are constrained in a couple of ways: Both must be positive (the density of anything can't be less than zero), and in order to make the universe "flat", Ω_m and Ω_λ must add to 1. "Flat" means that the universe does not bend in the fourth dimension. So the value of Ω_λ determines Ω_m , or vice-versa. There is another very interesting relationship between Ω_m and Ω_λ . It turns out that if $\Omega_\lambda > \frac{1}{2} \Omega_m$, the expansion of the universe must be accelerating! (See Carroll, Press and Turner, 1992, cited earlier, or "Introduction to Cosmology" by Barbara Sue Ryden, 2003.)

If we play with the values of Ω_m and Ω_λ keeping within the constraints, we can find the values that best fit the data. The optimum fit curve is shown in Figure 2:

Figure 2. The optimum standard cosmology curve.



Obviously it's an excellent fit! Standard cosmology provides a near perfect fit to the data! The optimum values of the parameters are: $\Omega_m = 0.280$ and $\Omega_\lambda = 0.720$. From these values we can conclude that the universe is indeed accelerating in its expansion since $\Omega_\lambda > \frac{1}{2} \Omega_m$ ($0.72 > 0.14$). IF you believe the theory, that is. And that's the trouble. General relativity (on which standard cosmology is based) has been around for close to a century, and it has withstood the test of time. Our confidence in the theory certainly lends credence to the conclusion that the expansion of the universe is accelerating is correct. But it's not the kind of evidence we'd really like – it's not direct evidence. We have no way of independently checking it. We just have to take the say-so of the theory, the theory's word for it. In addition, there's a problem with dark energy, the basis for Ω_λ – there's no direct evidence for it either. It's just a postulate of the theory! What we'd really like to do is measure the expansion of the universe with a stopwatch and a ruler and see for ourselves whether it's accelerating or not. Unfortunately that's impossible.

Another difficulty is that accelerating expansion of the universe is a totally counterintuitive result. Before the type Ia supernova data was obtained it was rejected as nonsense by most mainstream cosmologists. So perhaps the idea of accelerating expansion shouldn't be accepted quite so easily. Is there an alternative explanation for the unexpected faintness of distant type Ia supernovae that doesn't require an accelerating expansion and dark energy?

4 The Dynamic Universe Theory: the Expansion of the Universe is not Accelerating

We will begin this section by developing the DU equation for the distance light travels between two points (for example between a star and the earth) as the universe expands. Then we will use that relationship to derive the DU's equation for distance modulus versus redshift.

4.1 The DU Equation for Cosmological Distance

In standard cosmology there are several kinds of distance. Two of these are “proper distance” and “luminosity distance”. The proper distance, d_P , between, say, two stars is the distance we would measure if we instantaneously stopped all motion in the universe (froze it in a block of ice!) and stretched a tape measure between the stars. Proper distance is the actual tape-measure distance to an object “right now”. There is no practical way to actually measure proper distance.

A distance that we can measure is luminosity distance. If we know how bright an object is at its source, and we measure how bright it appears as seen from a distance, that kind of a distance is called a “luminosity distance”. For example, if a 100 watt light bulb casts, say, 3 watts of light on a sheet of paper 10 feet away, the paper's luminosity distance from the light bulb is 10 feet. The idea of luminosity distance from a distant galaxy is a little more complex. Because of the way it's defined, luminosity distance takes into account not just distance, but also the effects of the expansion of space while light travels from, for example, a galaxy to earth. Light consists of little packets of waves (“wavelets”) called photons. During their travel, the expansion of space causes the photons in a stream of light to lengthen and also the spacing between them to increase. Both of these effects reduce the brightness of the light.

In the DU, it is most convenient to use a third kind of distance, the “optical distance”, d_O , which is the distance light travels from a source to an object (from a star to earth for example) in three dimensional space (i.e., along the surface of the expanding 4-sphere of four dimensional space). Optical distance is different from the proper distance because optical distance takes into account the expansion of space during the time the light from a star travels to earth. It differs from luminosity distance in that it does not include the increases in length and spacing of photons during their travel. And it differs from both proper and luminosity distances because it is based on a different geometry of space. Figure 3 below shows the travel over expanding space of light from an object starting at a position A1 until the light reaches position B where we observe it.

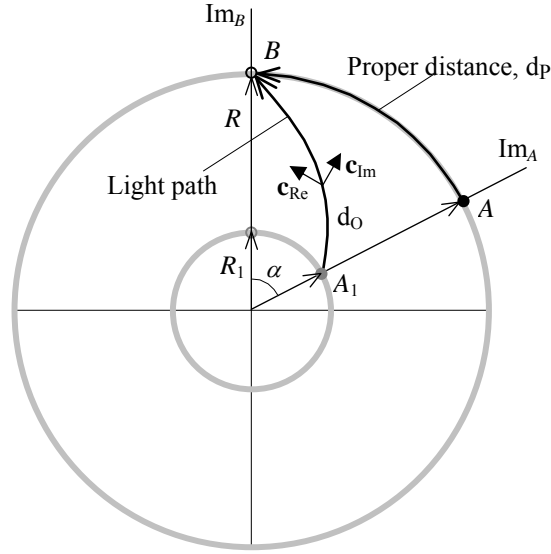


Figure 3. The physical distance, d_p , from object A to observer B at the current 4-radius R is equal to the arc $AB = \alpha R$. The optical distance, d_o , is equal to the tangential component of the spiral light path from A_1 to B . The tangential component is the distance in space, in the direction of the real axis in the complex coordinate system. Because, throughout the traveling path, the velocity of light in space, c_{Re} , is equal to the velocity of space, c_{Im} , in the imaginary direction, the optical distance light travels in space is equal to the increase the radius of 4-space from R_1 to R . That is, d_o , the summation of the real components of arc A_1B , equals $R - R_1$.

Because the speed of light in our three dimensional space is equal to the speed of the expansion of space along the 4-radius in the fourth dimension, the optical distance of light traveling from a star is equal to the increase of the 4-radius of space during the time of the light's travel. That is,

$$d_o = R - R_1, \quad (6)$$

where d_o is the optical distance, R_1 is the initial 4-radius, and R is the 4-radius when we observe the light from the star.

Also, the wavelength of light traveling from the star lengthens in proportion to the expansion of space. So we have,

$$z = \frac{\lambda - \lambda_1}{\lambda_1} = \frac{\Delta\lambda}{\lambda_1} = \frac{d_L}{R_1} = \frac{R - R_1}{R_1} = \frac{R}{R_1} - 1 \quad (7)$$

From the expressions in equation (7) we can obtain:

$$z = \frac{d_o}{R_1} \quad \text{and} \quad z + 1 = \frac{R}{R_1} \quad (8,9)$$

Dividing (8) by (9), we get,

$$\frac{z}{z+1} = \frac{d_o}{R} \quad (10)$$

And finally,

$$d_o = \frac{z}{z+1} R \quad (11)$$

Equation (11) is the relationship we were looking for. It expresses the distance light has traveled from a star (or any stellar object) we observe in terms of the object's redshift and R, the current 4-radius of the universe, which, for all the purposes for which we will use it can be considered a constant.

4.2 The DU Equation for the Type Ia Supernova Data

As stated earlier, the DU calculates magnitudes based on an object's observed flux:

$$m = -2.5 \log_{10} \left(\frac{F_{obs}}{2.53 \cdot 10^{-8}} \right) \quad (12)$$

Since we want the dependent variable (the horizontal axis in the figures) to be redshift, z, we need an equation that relates the observed flux to redshift, that is, F_{obs} to z. The equation is as follows:

$$F_{obs} = L_e \left(\left(\frac{z+1}{z} \right)^2 \cdot \frac{1}{4\pi R^2} \right) \left(\frac{1}{z+1} \right) \left(\frac{1}{(z+1)^2} \right) = \frac{L_e}{z^2 (z+1)} \cdot \frac{1}{4\pi R^2} \quad (13)$$

This equation gives the observed flux in terms of the redshift and the luminosity of a stellar object, specifically in our case, a type Ia supernova. To understand this equation, let's look at the terms, one by one. The first term, L_e , is the luminosity of the supernova, its total power. It's like the brightness of a light bulb, except that it's a whole lot brighter.

A type Ia supernova's power is equal to about $1.595 \cdot 10^{36}$ watts!

The second term, $\left(\left(\frac{z+1}{z} \right)^2 \cdot \frac{1}{4\pi R^2} \right)$, is the one we were preparing for in the previous section, 4.1. As distance from an object that radiates power increases, its power is spread over a larger and larger area. If the object were at the center of a hollow sphere with a radius of D (for "distance"), the power radiated by the object would be spread evenly over the inside of the sphere. The area of the sphere is given by the formula $A = 4\pi D^2$. To find the flux, the power per unit area, we divide the total power by the area it's spread over, $4\pi D^2$. Or, equivalently, we multiply by $\frac{1}{4\pi D^2}$. The distance we are interested in, in our case, is d_o , the optical distance we derived in the previous

section, which is given by $d_o = \frac{z}{z+1}R$. Substituting d_o for D in the multiplication factor, we get the second term in equation 13.

The third term, a factor of $1/(z+1)$, accounts for the effects of the expansion of space on light (a stream of photons) during its travel of from the supernova to earth. Over the course of their travel, the photons become stretched (their wavelengths increase) and spaced farther apart. In the DU, the stretching of the photons does not alter their energy, it merely spreads it out over a longer distance (if that were not the case, their energy would not be conserved!). Since photons always travel at the speed of light, increasing their spacing causes fewer of them pass through the shell of our hollow sphere per second, which, by definition, means the flux is reduced. The spacing between photons is stretched by the same factor that photons are (because space itself is stretched!). The stretching factor is λ_1/λ , where λ_1 is the wavelength of a photon at its point of its emission from the object, and λ is its wavelength measured by the observer on earth. This is equal to $1/(z+1)$: From the definition of z , we have

$z = (\lambda - \lambda_1)/\lambda_1$, and rearranging this equation gives $\frac{\lambda_1}{\lambda} = \frac{1}{z+1}$ the stretching factor that is the third term in equation 13.

The last term, $1/(z+1)^2$, is needed to remove the “K-correction”. The K-correction is an adjustment cosmologists make to their observed flux data. The K-correction has nothing to do with the DU, but we need to remove it so our equation will be consistent with the way data is published in the scientific literature. The factor $1/(z+1)^2$ is actually not precise, but is a very good approximation to the K-correction.

Substituting the result for F_{obs} in equation (13) into equation (12), we get:

$$m = -2.5 \log_{10} \left(\frac{1}{z^2 (z+1)} \cdot \frac{L_e}{4\pi R^2} \cdot \frac{1}{2.53 \cdot 10^{-8}} \right).$$

Since L_e is a constant for type Ia supernovae, and the current radius of the universe, R , is, over our lifetimes, for all practical purposes a constant, this reduces to:

$$m = 5 \log_{10}(z) + 2.5 \log_{10}(z+1) + \text{constant}.$$

Splitting the constant into two parts, the fixed absolute magnitude for a type Ia supernova, M , and a value to be determined, C , we get:

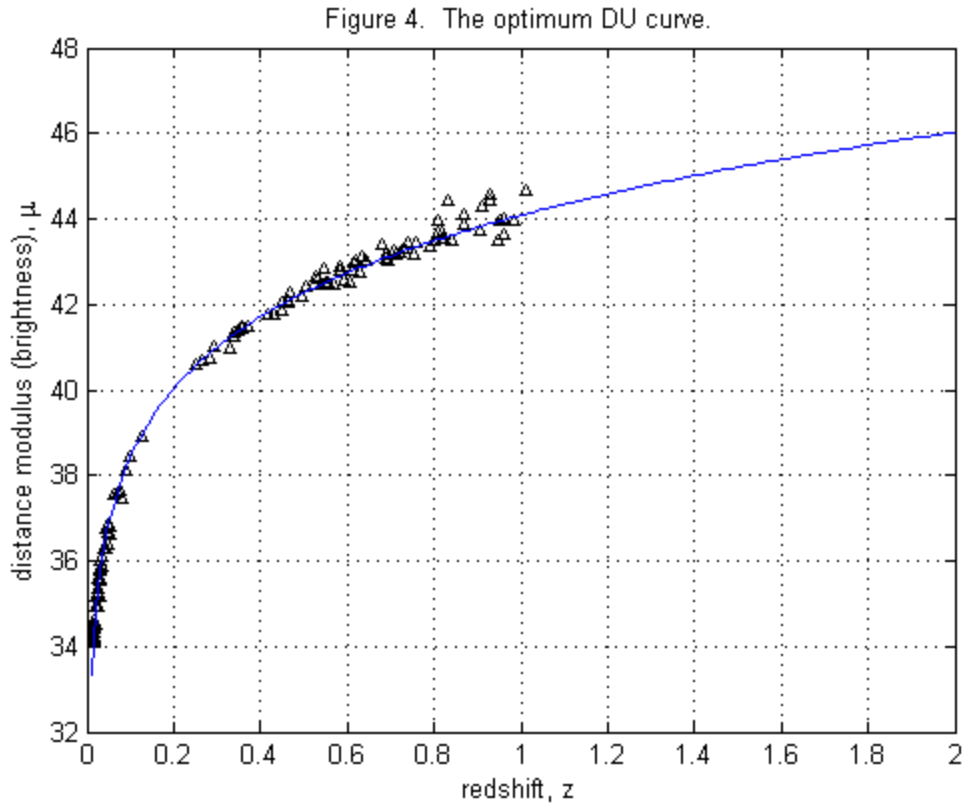
$$m = M + 5 \log_{10}(z) + 2.5 \log_{10}(z+1) + C.$$

Or equivalently,

$$\mu = m - M = 5 \log_{10}(z) + 2.5 \log_{10}(z+1) + C,$$

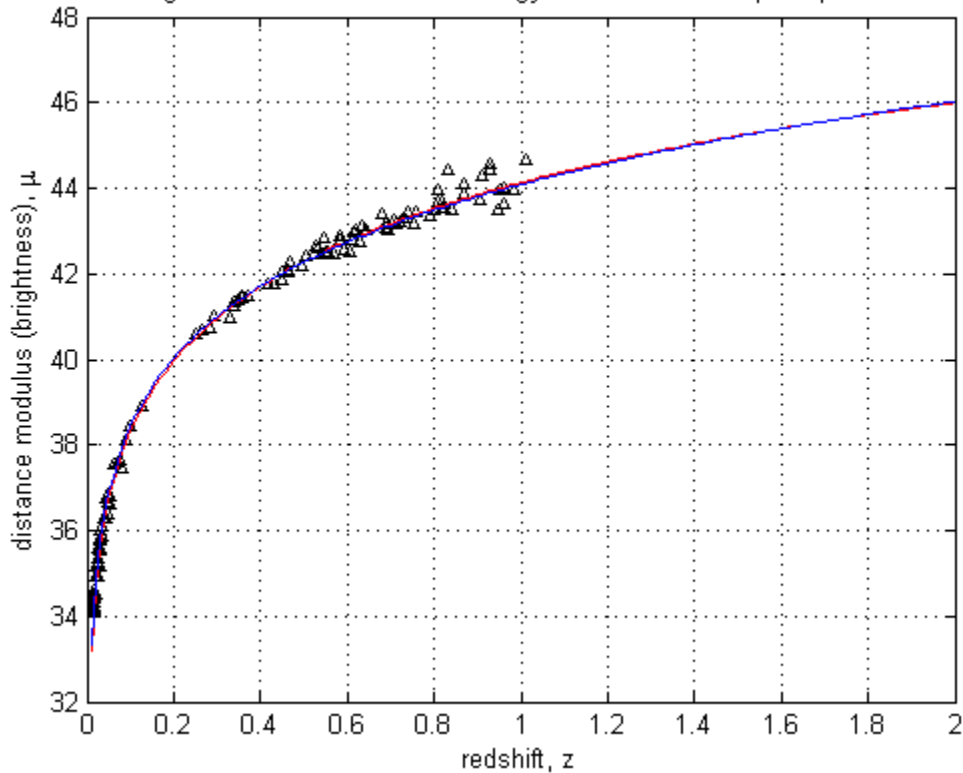
which, finally, gives the DU equation for the distance modulus in terms of the redshift, z .

Figure 4 shows the optimum fit of the DU equation.



Obviously it's another near-perfect fit. The value of the constant C that optimizes the fit of the curve is 43.330. Both the standard cosmology and the DU curves model the data extremely well. Let's lay them on top of each other to see how the two curves compare:

Figure 5. The standard cosmology and DU curves superimposed.



The curves are all but identical. A mathematical “goodness of fit” (GF) value I computed reveals just how close the two curves are. The GF number for the standard cosmology curve is 31.5859; for the DU it was 31.5262. A smidge better (smaller) for the DU, but the difference is so small that the normal random inaccuracy in the measurement of a single data point could probably account for it.

Still, the DU fit in comparison to that of standard cosmology may be even better than it looks. The standard model adjusts two parameters to optimize the fit: M which moves the curve up or down, and Ω_λ which adjusts the shape (curvature) of the curve. The DU has just one adjustable parameter M , which moves the curve up or down. In the DU, the shape of the curve is fixed. The greater the number of parameters in an equation that is used to fit data, the better it is possible for the fit to be. But that also increases the chance that the model is wrong. For example, a parabola (which has three parameters) fit to data points that are randomly scattered around a straight line (which only has two parameters) will have a better GF value than the straight line. This is so because the randomly scattered data points will, almost inevitably, have just a tad of curvature.

Conclusion

The big difference is not in the curves but in the theories! In order to explain the data, standard cosmology requires the expansion of the universe to be accelerating. The DU has no such requirement. Which theory is right? On the basis of the type Ia supernova data, the DU has a small advantage. The theories model the data equally well, but the DU model does it with only one parameter instead of two. Another advantage for the DU

is that it doesn't need to postulate a new force, dark energy, to explain the data. On a wider scale, the DU has been found to be in complete agreement with the theory of general relativity (on which standard cosmology is based). As examples, phenomena that general relativity and the DU model equally well include: the tradeoff between mass and energy, the rotation of the perihelion of Mercury, the bending of light around stars, and the slowing of clocks in a gravitational field.

Here are some Internet links to more information about the DU:

1. "The Dynamic Universe Theory – a Theory of the Universe that Makes Sense!" at <http://bobday.vze.com>
2. Dr. Suntola's website:
<http://www.sci.fi/~suntola>
3. "Theoretical Basis of the Dynamic Universe" by Tuomo Suntola:
http://www.amazon.com/gp/product/9525502104/sr=1-1/qid=1156529058/ref=sr_1_1/102-3325681-5207315?ie=UTF8&s=books

Figure 3 in this essay is courtesy of Dr. Tuomo Suntola. I have modified Dr. Suntola's original figure to adapt it for this essay, so I'm to blame for any inaccuracies.