Standard candles and the accelerating universe revisited.

This note investigates whether the data presented by Saul Perlmutter on redshifts and standard candles necessarily leads to the conclusion that the expansion of the universe is accelerating. In this letter a simple model is presented with a constant rate of expansion which nevertheless predicts the relationship between redshift and distance found by Saul Perlmutter and others. Initially this model is presented simply to indicate that Permutter's conclusion of an accelerating rate of expansion for the universe is not necessarily correct. The model does however predict the data collected by Perlmutter et al extremely well, it predicts precisely the same redshift vs observed distance relationship as found by Perlmutter et al, and it is speculated whether, despite certain objections, it could be correct after all.

If we start with Perlmutter's own words (Box below)

> **Searching for a standard candle.**[1]
>
> In principle, the expansion history of the cosmos can be determined quite easily, using as a "standard candle" any distinguishable class of astronomical objects of known intrinsic brightness that can be identified over a wide distance range. As the light from such beacons travels to Earth through an expanding universe, the cosmic expansion stretches not only the distances between galaxy clusters, but also the very wavelengths of the photons en route. By the time the light reaches us, the spectral wavelength l has thus been redshifted by precisely the same incremental factor $z = \Delta\lambda/\lambda$ by which the cosmos has been stretched in the time interval since the light left its source. That time interval is the speed of light times the object's distance from Earth, which can be determined by comparing its apparent brightness to a nearby standard of the same class of astrophysical objects.
>
> The recorded redshift and brightness of each such object thus provide a measurement of the total integrated expansion of the universe since the time the light was emitted. A collection of such measurements, over a sufficient range of distances, would yield an entire historical record of the universe's expansion.

The contentious phrase is 'That time interval is the speed of light times the object's distance from Earth'. It is not obvious that this is correct. It would be correct in a static universe but that would be clearly inconsistent with an expanding universe. The problem is that the universe is expanding. This both increases the distance between the observed object and the observer as light travels between the two, and it also adds to the speed of a photon on this journey.

Does this matter? Perlmutter et al can plot their data as scale factor vs distance, rather than scale factor vs age, and they might still come to the conclusion that the the expansion of the universe is accelerating. However, now this conclusion only holds if the universe is flat.

The problem can be illustrated by assuming a simple model for the expanding universe, such as a sphere expanding at a constant rate. The universe cannot be a 2-sphere, which is a 2-dimensional object, nor a 3-D ball (it would have a centre and an edge and not be isotropic) but it could be a 3-

sphere. A 3-sphere is the surface of a 4-D ball; it is a 3-dimensional object embedded in four dimensions. Additionally assume that this sphere is expanding at the speed of light. Figure 1 shows a cross section through an expanding 3-sphere with 14 timesteps, each of 1 billion years.

Consideration of the turquoise stepped line indicates that the path of light arriving at the observer, B, in this universe, follows an equiangular (logarithmic) spiral with an angle of 45 degrees. This is shown by the red curve. Next, consider an object with a redshift of 1 and a scale factor of 2. If the universe is expanding at a constant rate this object will exist in the universe when it was 7 billion years old. Following the path of light to the 7 billion year old universe, locates this object at the point labelled 7. As light travels from point 7 to the observer, at B, the object expands with the universe to the point labelled R1. Now the distance from the observer to the point R1, through the present day universe, ie around the circumference (the co-moving distance?) is a little over 9.5 billion lightyears. This is the distance that would be measured using a standard candle and is also the correct distance to use with Hubble's

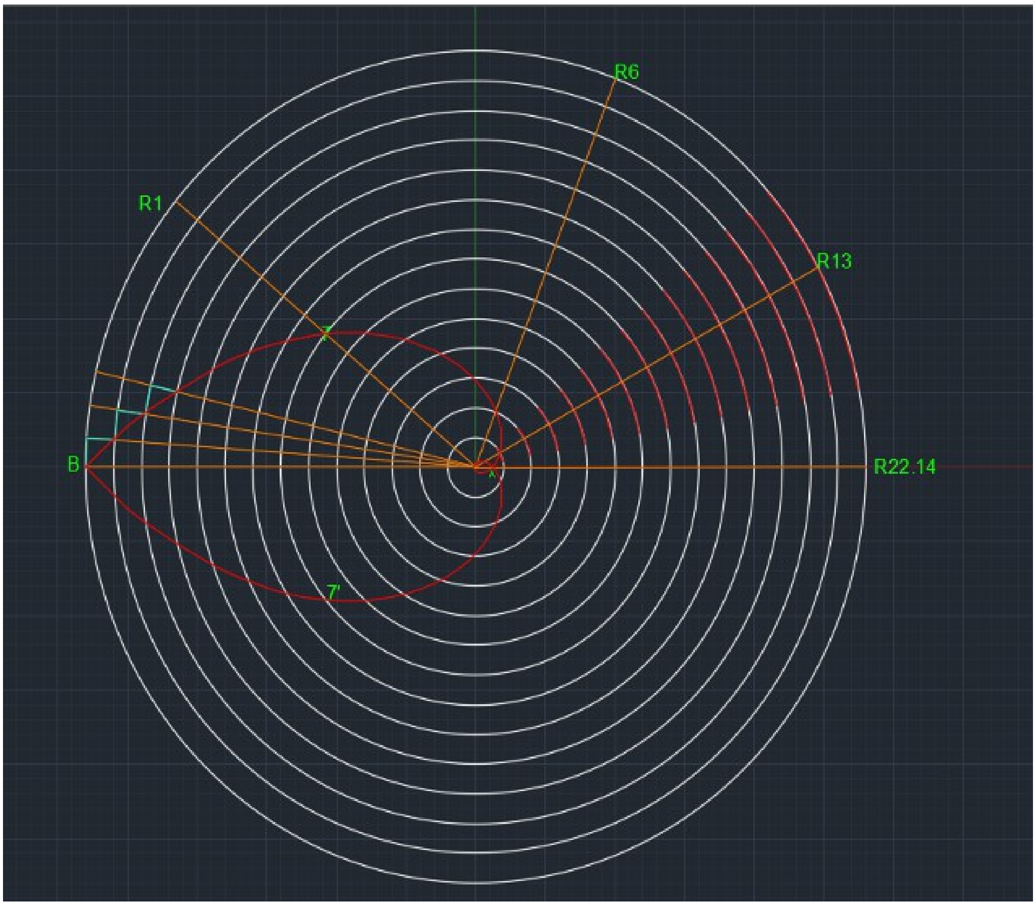

Figure 1. Cross section through an expanding 3-sphere with 14 timesteps, each of 1 billion years.

Law. It is also the distance measured by Perlmutter to the galaxy with a redshift closest to one in his data set. This model can be used to calculate the distance to any object with a given redshift or scale factor (the scale factor, s.f. equals the redshift plus 1). This is shown in Figure 2.

In Figure 2 the orange curve shows 1/scale factor vs distance calculated from the 3-sphere model. At first site this seems to support the conclusion that the expansion of the universe is accelerating. But this is only true in a flat universe. When 1/scale factor is plotted against the age of the universe, as calculated from the 3-sphere model the blue lines are the result, which indicates that in this model the universe is expanding at a constant rate, which is of course the original assumption.

The Perlmutter data on redshift (converted to 1/scale factor) vs distance (obtained from the standard candles) is also shown in Figure 2. The agreement with the 3-sphere model when the rate of expansion is set equal to the speed of light, is striking.

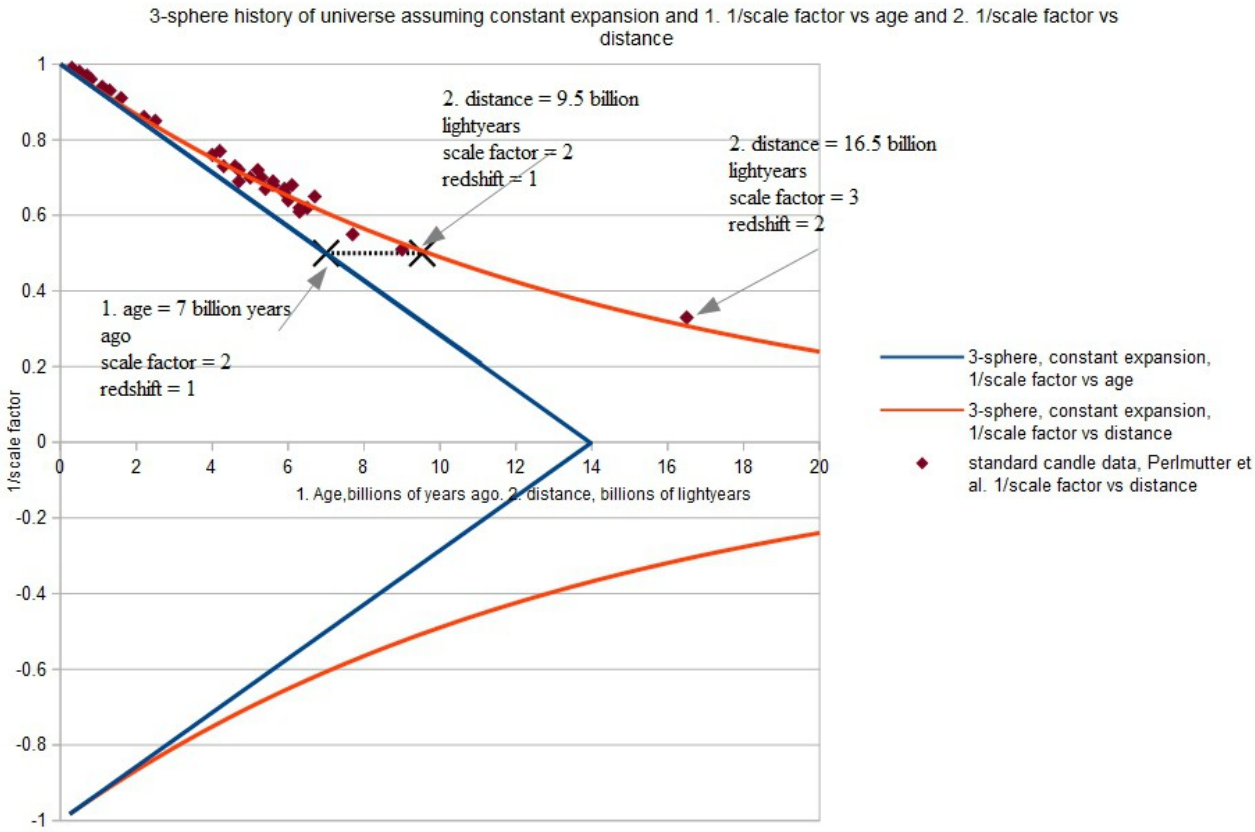

Figure 2, Evolution of the universe according to the 3-sphere model. 1/scale factor vs age (blue line) and 1/scale factor vs distance (orange line)

So far a model of the universe has been selected simply to show that Perlmutter's treatment of his standard candle data is not necessarily correct. But in fact the model used, a 3-sphere expanding at the speed of light, fits Perlmutter's measurements extremely well, so it is interesting to speculate whether it could be correct. Others, including at one time Einstein, have considered such a model for the universe. The main reason for discounting it is that, without modification, it is not consistent with general relativity. Now, if the universe is a 3-sphere, it has certain analogies with a black hole. In particular, a photon moving in a 3-sphere universe is effectively in orbit (all points in a 3-sphere are equidistant from its centre). If so, with a fixed velocity, the speed of light, and a fixed radius, 14 billion light years, then, using the Schwartzchild relationship, or just simple Newtonian mechanics, the mass of the universe is fixed. Currently it is 8.9 x 10^{52} kg. This gives a density of 1.9 x 10^{-27}

kg/m^3, around 33% of the critical density. But the mass of such a universe must increase as it expands, in proportion to the radius (the density reduces in proportion to the radius squared). (An alternative is that the gravitational constant must increase as the universe expands, but an increasing mass seems simpler). It is speculated that the requirement for the mass of the universe to increase in proportion to the radius, could bring the 3-sphere model back into line with general relativity or perhaps instead lead to some acceptable modification of general relativity. It is not necessary in this scenario that new matter is created. It is most likely that additional mass is due to the vacuum energy of additional space.

The 3-sphere model also predicts a Hubble constant very close to the currently measured value and explains why the reciprocal of the Hubble constant equals the age of the universe.

Finally the standard λ CDM model for the universe does not predict inflation, nor, at first sight does an expanding 3-sphere model. But on closer inspection, the 3-sphere model predicts inflation extremely well. Figure 1 shows a light path following an equiangular spiral. This spiral never reaches the centre (the point of the big bang) but continues to circle the centre getting ever closer. In fact each circuit reduces the radius of the universe by a factor of around 530. And it takes around 23 circuits to reach the Planck sized universe. Each circuit would have an apparent (co-moving?) length of 88 billion lightyears, giving an apparent distance of 40 trillion lightyears to the Planck sized universe. If a photon from the Planck sized universe made it through to the present day, it would have a redshift of 10^{61}. More importantly it would seem to have been travelling at 10^{61} times the speed of light. As seen from the vantage point of our current universe, the Planck sized universe would seem to have been expanding at 10^{61} times the speed of light. This would seem to adequately explain inflation. In fact nothing ever travelled faster than the speed of light, inflation is a virtual phenomenon.

It is suggested that it is worth making further investigations into whether a 3-sphere expanding at the speed of light could, after all, be a valid model for our universe.

References

1. Supernovae, Dark Energy, and the Accelerating Universe. Saul Perlmutter. Physics Today, April, 2003.