

DISTANT GALAXIES AND COSMOLOGICAL MODELS

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Observational Findings

How can we tell which of these models comes the closest to describing our real universe? As mentioned above, it presently appears that the actual mass density of our universe is perhaps 1/3 or so of the critical density, suggesting our Model IV or Model V. Also, measurements of the sizes of ripples in the CMBR, discussed below, suggest a flat universe, favoring Model V. There have been some very recent measurements which are quite suggestive. Certain supernovae have an absolute luminosity which can be closely determined from the time history of their flaring up and dying away. This makes them somewhat like "standard candles" and is thought to give us a good basis for looking at their apparent luminosities (a measure of distance) and their redshifts (a measure of velocity of recession). If these results are plotted as relative magnitude Vs. redshift, different cosmological models give slightly different shape curves. **Figure VIII** shows the shape of three curves for our models II (very low mass density), III (critical density of the Einstein deSitter model) and V, the model with a present cosmological constant equivalent energy density of about 0.7 and a mass density 0.3 critical and therefore with a universe undergoing acceleration at the present time.

The very recent experimental measurements **(6)(7)** for some 20 or more supernovae fit best the line for the accelerating universe with the non-zero cosmological constant! Detailed graphs are included in these references showing how the observed data points fall. Since these measurements were made more supernovae have been measured with similar results. There will be a lot of interest in this model in the months and years to come. Many more measurements of supernovae will be made. The differences among these models are reflected in the

differences in the shape of the curve for $R(t)$. A simple picture of this curve shape for Models III and V is given in Sky and Telescope(8).

For our Model III the relation is:

$$R(t) \sim t^{2/3} \text{-----(4)}$$

For our Model IV an approximate fit is:

$$R(t) \sim (t^{2/3} + at) \text{-----(5)}$$

For Model V an approximate fit to recent supernovae data is given by:

$$R(t) \sim (t^{2/3} + ae^{bt}) \text{---(6)}$$

Some cosmologists are still thinking of a model close to our Model IV with about 1/3 the critical density but no cosmological constant. Since the Einstein deSitter model of our Model III permits an exact solution for the model parameters and describes flat space, it is used as well by some cosmologists to report their results.

Quite often, reports in the press and in magazines like Scientific American, Science and Science News report cosmological data without mentioning which model is being used. In addition, usually the concept of distance being used is not mentioned either and whether it is distance now or distance then. It looks as if the **light travel distance** is used in many cases rather than any proper distance and frequently it is Model III, the Einstein deSitter model which is being used in published papers for the general public. Also, at times, the relativistic Doppler shift equations are used rather than the cosmological redshift ones. An article in Science News for April 17, 1999, for example, says "...a galaxy 14.25 billion light years from earth.....the light.... left the galaxy when the universe was just 5% of its current age.....has a redshift of 6.68".

It looks as if the Einstein deSitter model is being used with an age of the universe of about 15 billion years. The lookback time is 14.25 billion years and thus the distance quoted appears to be the light travel distance. The proper distance now is much greater than 14.25 billion light years and the proper distance then was much less. The redshift of 6.68 fits our Model III and

Figure III for this value of lookback time. Observations at redshifts of 8 and 10 give the lookback times (and light travel distances) which also fit our Figure III.

In principle, another way to differentiate among the models is to look at the count of galaxies within a certain solid angle out to a certain distance as a function of distance as expressed by the redshift. The difference between our Model II and Model III is shown in [Figure IX](#) for a universe with uniformly distributed galaxies. There is quite a difference in the value of z at which the curves reach their maximum since the models are quite different in the volume of space within a given redshift. This technique is discussed in Peebles(4) pages 331-333 where it is indicated that this could be a powerful tool. Unfortunately, in our universe, galaxies are not uniformly distributed, we have galaxies, galaxy clusters, galaxy superclusters and the "great wall" of galaxies. There are also questions as to whether there were galaxies of similar number and size in the very early universe, so this approach is not yet very helpful. Perhaps, in time to come, much more data will be gathered and this picture might also help to differentiate among the models. It is also possible that galaxy observations may clarify the question as to whether our universe is multiply connected as mentioned above.

A more fruitful line of investigation appears to be to measure the CMBR with extreme accuracy to notice slight differences in signal strength in small regions of the sky and to note the distribution of the angular size of these differences and thus to deduce the values of some of the key cosmological quantities of these models. There is active research going on in this field. From an analysis of the very early universe when radiation and matter were not decoupled "ripples" can be predicted and the spectrum of their sizes as well. When we observe these ripples in the CMBR their size spectrum gives us an indication of the curvature of the universe. For a flat universe the first major peak in the spectrum should be at about 10° . Recent measurements are consistent with a flat space model as indicated in a Sky and Telescope article(9). Even more recent measurements further support this result and indicate a flat universe. See the May 2004 article in Physical Review Letters mentioned above in [Latest News](#).

With the Hubble telescope and the advent of larger ground-based telescopes and continuing improvement in detection techniques, more and more will be learned about this fascinating and awe-inspiring universe of ours and it might well be that the accelerating universe model may win out and perhaps the multiply-connected universe of the Scientific American article(3) as well. There are three articles on cosmology touching on many of these same points in another Scientific American issue (10)(11)(12) .

It appears that many, if not the majority, of cosmologists presently seem to favor this Model V with an accelerating universe. There is a problem, however, in explaining the absolute magnitude of the cosmological constant which seems to be necessary to fit the observed astronomical data from supernovae and from the CMBR. This value for the cosmological constant is many orders of magnitude smaller than the value which would be derived from quantum mechanical analysis of the properties of empty space. It would be nice to be able to show why the cosmological constant has the value it does and why the values for W_i and W_m are so close at the present epoch.

A cosmologist favoring Model IV, on the other hand, has to struggle with the evidence from supernovae, the evidence for a flat universe and yet the evidence for a mass density well below critical. Many more measurements of supernovae will be made and there will be many more galaxy luminosity and redshift measurements and galaxy counts in the next few years. There will be many more searches for dark matter and measurements of the CMBR. A whole new chapter of x-ray spectroscopy is beginning with the x-ray satellite Chandra now in orbit with others to follow soon permitting other explorations of dark matter and background radiation. Keep tuned. We are in a very rich and productive period for cosmology. Two candidates for dark matter are Machos (massive compact halo objects) and Wimps (weakly interacting massive particles). Machos could be ordinary baryonic matter (protons and neutrons) but Wimps would be something else. Much more needs to be done to determine the nature of dark matter.

The evidence for an accelerating universe seems to be strong.

The evidence that space is flat seems to be strong. The evidence that matter density including dark matter in halos around galaxies and galaxy clusters is still only about 1/3 critical appears to be strong. The uncertainty today is mainly in the question as to whether there really is a cosmological constant as presently envisaged or whether some other as yet unknown effect is in play. This situation is thoroughly described in "Living with Lambda" by J. D. Cohn (13)

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