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Crucial tests in cosmology

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Abstract. We discuss here a few basic tests of cosmological models which are potentially able to disprove the big bang paradigm. These include (a) the search for blueshifts, (b) the search for very old stars, (c) the identification of baryonic dark matter, (d) precise determinations of light nuclear abundances, and (e) the confirmation of anomalous redshifts. We will also discuss how the quasi-steady state model is expected to behave in these tests.

1. Introduction

Let me begin by wishing the Uttar Pradesh State Observatory a successful future as it celebrates the silver jubilee of its Sampurnanand Telescope and plans for more ambitious observing programmes. Since this meeting is convened to mark this occasion, it would not be out of place if I emphasize here the importance of observational tests for cosmology. This talk underscores the ways in which the currently popular big bang cosmology can be tested by observations. I hope that the UPSO may be involved with some of the tests mentioned here.

Karl Popper has stressed the importance of falsifiability of a scientific paradigm. Contrary to the general belief that tests in favour of a paradigm strengthen it, the real strength of a paradigm lies in its surviving a test which could potentially disprove it.

The currently popular big bang paradigm is one case to point. It is claimed that the paradigm receives support from (a) the microwave background, (b) the abundances of light nuclei and (c) the evidence for evolution. Historically speaking, these were the tests on which its rival, the steady state theory was claimed to have been disproved. The fact that they are well satisfied by the big bang model does not grant it the status of uniqueness as a cosmological theory. There could be other theories which also meet these criteria. What one needs are tests which, if they yield positive results would *disprove* the big bang paradigm. If the paradigm survives such tests, it would receive greater credibility. We will look at a few such tests.

The basic big bang model comes with several optional extras. The main ones are :

i) Hot big bang.
ii) Hot big bang with inflation,
iii) Hot big bang with the cosmological constant,
iv) Hot big bang with inflation and cosmological constant.

Further optional extras come in the form of cold / hot / mixed dark matter. We will consider five tests which can be used for disproving these models.

2. The search for blueshifts

All models mentioned above assume that the universe has been expanding at all epochs in the past, and as such, all extragalactic objects in it would show a redshift. The discovery of even a modest blueshift of the order of 0.1 will be sufficient to disprove these models. For, $z = -0.1$ will require an approaching Dopplerian speed of the order of 30,000 kms^{-1}, which cannot be ascribed to random (peculiar) motions.

One may ask, why with so many redshifts found till today there has not been a single case of a blueshift (barring of course the very first one to be found, for the Andromeda galaxy)? There are, however, some selection effects which operate against a positive result being found from observations.

Firstly, the observers tend to look for rest wavelengths of familiar atoms on the short wavelength side of the observed spectral line. The same applies to multiple line spectra wherein the ratios of wavelengths are compared with those on the short wavelength side. Thus there being no deliberate searches for blueshifts, none are found.

Secondly, it may happen that the universe has been oscillating with large time scales (- we will discuss such a possibility towards the end of this talk) and the era of blueshift may be rather far in the past. Thus one may need to do spectroscopy of rather faint galaxies to discover blueshifts, not an easy task if the required magnitudes are as faint as 26^m or more.

A third reason is that blueshift enhances the continuum and against a bright continuum, it becomes difficult to spot individual lines.

A fourth reason could be that intergalactic absorption may be higher for blueshifted sources, making it more difficult to find them.

Thus, it may be worthwhile to look more carefully at lineless objects and also those with single line redshifts. Perhaps a blueshift is lurking there in the form of a misidentified line. As spectroscopy of very faint galaxies becomes possible, searches for blueshifts may be tried.

3. Very old stars

The big bang models are known to face an age problem (see, for example, a discussion in

Bagla, et al). With a Hubble constant of 65 Km s^{-1} Mpc^{-1}, a standard inflationary ($\Omega_0 = 1$) model gives the present age of the universe as 11 Gyr. This falls short of the ages of globular clusters currently estimated in the range 12 - 18 Gyr. There is an uncertainty in the age determinations. Also, using a cosmological constant, the age of the universe can be increased. However, if we succeed in finding stars as old as, say, 40-50 Gyr, there is no way the big bang model can accommodate them.

It is customary to date stars from the epoch when they leave the main sequence and go along the giant branch. This is because, the bulk of a star's life is spent on the main sequence and its lifetime as a red giant is relatively short.

The dating of globular clusters, which gives ages in the range of 12-18 Gyr, is done on this basis. The stars chosen are usually of the solar mass order. The theory of stellar evolution tells us that the normal time scale for evolution as a main sequence star increases rapidly as we lower the mass of the star. Thus a star with half the solar mass may take 40-50 Gyr to evolve off the main sequence. Such a star will appear as a low mass giant.

Russell Cannon (1996) has pointed out that the magnitude at turn off from the main sequence for 50 Gyr old stars will be only 2 magnitudes fainter than the solar mass turn off. As such these stars would be easily detectable and clusters of these stars would be recognized as ancient from their colour magnitude diagrams. The problem of course is that if a cluster contains stars of varying masses, over a period of 50 Gyr all the massive stars of solar mass or more will have burnt out and only the slow burning low mass stars will be left. Thus it is doubtful if these clusters will appear in the normal cluster catalogues.

Cannon (op. cit.) has pointed out that there is another way one could look for old low mass stars. The horizontal branch which is a prominant feature of the colour magnitude diagrams of standard clusters comprises stars which have undergone a helium flash and have two energy sources. However, stars with low mass, say around half a solar mass (after allowing for any mass loss) will not undergo a helium flash. Thus the integrated colours of the colour magnitude diagrams of the ancient clusters of stars will be different from that of standard clusters.

Another possible way is to look for very old white dwarfs, if one can correctly estimate how the luminosity of a white dwarf would vary over a time scale of 40-50 Gyr. If we assume that typically white dwarfs cool to around 10 percent of their luminosity in 10 Gyr, the white dwarfs of 40-50 Gyr will be very hard to detect, assuming the cooling rate is exponential.

4. Baryonic dark matter

It is now generally accepted that there is dark matter in the universe which may exceed its visible counterpart. How much dark matter is there in all? How much of it is baryonic? In the big bang models, the parameter Ω_0 determines the matter content of the universe. The dynamics of the universe will depend on this parameter as well as the cosmological constant.

However, there are other implications from the second question.

Firstly, the baryonic part interacts with radiation and as such its fluctuations would have influenced the fluctuations of radiation in the early stages prior to the last scattering surface. The COBE and other observations place stringent limits on $\Delta T / T$ and rule out the possibility that all matter is baryonic. In fact, structure formation scenarios require a large fraction of matter to be non-baryonic.

A second constraint comes from deuterium abundance, which would become negligibly small if the baryonic component Ω_{baryon} were to exceed $0.02h^{-2}$, where the Hubble constant is $100h$ kms^{-1} Mpc^{-1}. This is perhaps the tighter constraint to satisfy.

So, if through observations like those of hot gas in clusters, or of the brown dwarf / planetary mass objects found by MACHO/EROS type microlensing studies, it is established that the baryonic component exceeds the above limit, then it will be a disproof of the big bang paradigm - unless some ingenious loophole is found.

5. Light nuclear abundances

Contrary to the general impression that light nuclear abundances are very well explained by the big bang nucleosynthesis, there are problems which require fine tuning of the available parameters, in particular the photon to baryon ratio. For example, we saw how the deuterium abundance is critically dependant on this ratio. The abundances of Li, Be, B etc. also place constraints on the primordial nucleosynthesis picture.

The question of making these light elements in other ways has been discussed recently by Hoyle et al. (1993) and another workable scenario has been found. This scenario makes use of a different part of the density / temperature space than the standard big bang nucleosynthesis.

I feel that more data on the abundances of Li and Be will be decisive in telling us which, if any, of these two possibilities work. These data are important for the potential threat they pose to the big bang paradigm.

6. Anomalous redshifts

This last type of evidence hits at the very basic tenet of the big bang paradigm. It poses the question :

Is the redshift of every extragalactic object due solely to the expansion of the universe?

If we accept the expanding universe idea as the basis for cosmology then the answer to this question has to be YES. Which means that the establishing of counter-examples will disprove the idea.

The direct consequence of the expanding universe idea is that there is a unique relation of the type

$$z = f(D)$$

between the redshift z and distance D of any extragalactic source. Thus to disprove the idea one should demonstrate that at the same distance D from the source, we can find two objects with different redshifts. In other words, we need to show physical associations of two objects (at least) of different redshifts. We typically have one object in the pair obeying Hubble's law, while the other, with excess redshift, will have anomalous component in its redshift.

Evidence of this kind exists; indeed it has existed for about twentyfive years. For details of the science and sociology of this type of evidence see the book by H.C.Arp (1987), which gives numerous references to publications of such instances in reputed and refereed international journals. Yet, because of its disturbing implications for cosmology, this type of evidence has been ignored or discounted. Basically it gives cases of the following types :

Quasar-galaxy associations
Galaxy-galaxy association
Quasar-quasar association
Filamentary connections between objects of different redshifts
Very special alignments of objects of different redshifts
Periodicities in redshift distributions etc. etc.

In each case the conventional viewpoint has to argue that what is seen is not real but the effect of a random projection. However, if one computes probabilities for random projection, one gets very low values, much less than 10^{-2}, sometimes, as low as 10^{-5}.

Today this subject is bogged down with controversies concerning the reality of the effect observed, the computed probabilities, and effects like gravitational lensing brought in to explain the observations. I believe that the picture will clarify not by ignoring these cases but by probing them more deeply.

7. Conclusions

I have concentrated here on the big bang cosmology because it is the 'best sell' model in the cosmological shopping plaza. Tests described above satisfy Popper's criterion that they can potentially disprove the theory if it is basically wrong.

Nevertheless it is worth comparing the results for the quasi-steady state cosmology (QSSC) of Hoyle et al. (1993). In this cosmology the universe expands with a scale factor given by

$$S(t) = \exp(t/P).\,[1 + \eta\cos\theta]$$

where θ is a function of time t which approximately equals $2\pi t/Q$. The parameter η has magnitude less than unity. Thus this cosmology has a long term exponential expansion time scale P and a short term oscillatory time scale of period Q. Hoyle et al. (op. cit.) have estimated that P is about 20 times Q and Q is around 40-50 Gyr.

In this cosmology there is no big bang; the universe has no beginning and no end. Matter is created in this universe in small doses, called the mini-creation events or *minibangs*. These events are not singular, however, in the sense the big bang is. They are described by a field theory within the framework of a set of Einstein-like field equations.

This cosmology predicts that very faint galaxies (magnitude > 26) belonging to the previous cycle seen at an epoch close to that when the scale factor was maximum, should show a modest blueshift of order 0.1. Also, there is no 'age' problem here and low mass stars as old as 40-50 Gyr are expected. Further, the deuterium production in this model does not impose any restriction on baryon density, nor does the production of microwave background impose any limit on it from the standpoint of $\Delta T/T$. Thus all dark matter could be baryonic without disturbing the QSSC. The scenario for production of light nuclei also requires a high temperature phase such as found near a minibang, although the part of the density-temperature space relevant for this model is quite different from that used in the big bang nucleosynthesis.

The findings of anomalous redshifts will, however, require special treatment and new physics in the QSSC, just as for the big bang cosmology.

References

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