THE COSMOLOGICAL DEBATE: BIG BANG VS QSSC

By

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The Standard Model

The standard model in any subject denotes the well accepted model that generally describes successfully all the important observed features in that field. Thus the particle physicists have the standard model based on the group structure $SU(3) \times SU(2)_L \times U(1)$. The standard model for superconductivity is the BCS model. One could go back in history and say that the standard model for describing planetary motion in the last century was the Kepler-Newton theory. And so on.

It is not expected that a standard model shall remain standard for all times. The progress of science is such that the addition of new observations requires the standard model to be modified or even abandoned. Indeed, scientists are always in search of ways in which this can be achieved. The Kepler-Newton standard model thus gave way to general relativity when the various solar system tests, like the advance of the perihelion of Mercury, the bending of light, the radar echo delay, etc. so warranted, The high energy accelerator experiments are all the time testing the predictions of the standard model in particle theory.

In cosmology, over the years the so called hot big bang model with an inflationary phase in the past has acquired the role of the standard model. This model envisages the origin of the universe in a singular event which released matter in very high (literally infinite) state of energy. The big bang signifies this state of explosion and the universe so created began to expand with progressively decreasing speed. Its temperature dropped, density decreased as time passed and so did the energy of a typical particle in it. It is very likely that in the very first moments, upto an age of $\sim 10^{-43}$ second, the behaviour of the universe was as per the rules of quantum gravity, a subject whose details are still to be undrstood. Assuming that thermodynamic equilibrium prevailed at this stage, the typical equipartition energy per particle would be 10^{19} GeV.

As the universe expanded further, it cooled and this energy also dropped. Typically, the energy-time relationship was:

$$t_{\text{second}} = 2.4 \times 10^{-6}\, g^{-1/2}\, E_{\text{Gev}}^{-2},$$

where g denotes the number of internal degrees of freedom of the particle species suitably weighted to take account of whether they are fermions or bosons.

Thus, when the time elapsed was around 10^{-36} second, the particle energy dropped to just below 10^{16} GeV, the characeristic energy for a grand unified theory (GUT) as per the standard model of particle physics. This state therefore brings about a phase transition of the cosmological medium, leading to a drop in the energy of the true vacuum (the state of lowest energy).As this transition is being brought about, the change of vacuua generates an energy momentum tensor of the form $-\lambda g_{ik}$.

This extra term is very similar to the cosmological constant term introduced by Einstein in 1917, only its magnitude is some 10^{108} times higher. The result is that during this transitional stage when this term dominates the dynamics of the universe, the expansion is given by an exponential term of the form $\exp(\alpha t)$, where the constant α has the order of magnitude determined by the l term. The exponential expansion is the same as that in the old de Sitter model of 1917, only the constant α is much smaller in the modern version and it lasts for a limited duration.

This is the *inflationary phase* and it produces the effect of wiping out the spacetime curvature down to a very negligible value. Thus it essentially reduces the subsequent expansion of the universe to the Einstein-de Sitter model, which has the curvature parameter k equal to zero.

The big bang cosmology essentially subscribes to this as the standard model and all interpretations of the observed details of the universe are geared to this model. We shall refer to this as the standard model.

Strengths and Weaknesses of the Standard Model

We will briefly discuss the strong points of the above model first, to highlight why it is so popular amongst cosmologists. We will then discuss some of its weaknesses so as to make a case for devoting the rest of this article to an alternative cosmology.

Strengths of the standard model: 1. The big bang model predicts that the univers expands after creation. The expansion of the universe leads to the phenomenon of redshift z which was first systematised by Edwin Hubble in 1929 under the linear law:

$$v = cz = H_0 \times D$$

where v is the radial velocity of a typical extragalactic source of light, and D is its distance from us. The velocity of light is denoted as usual by c, and the constant of proportionality, now known as *Hubble's constant* is today estimated at a value of ~ $[9.8 \text{ years}]^{-1}$ h, h being a dimensionless parameter whose value is expected to lie between 0.6 and 0.8.

The first expanding universe models were worked out by Alexander Friedmann during 1922-1924, and are the same models used today, except for the inflationary phase. Hubble's discovery was therefore anticipated by the standard model. It is always a strength of the theory if it *predicts* a major observation. The Hubble law seems to hold out reasonably well to distances several hundred times those originally measured by Hubble. We will however, point out a few chinks in its armour towards the end of this article.

2. The work by George Gamow in the mid-1940s had proposed that during the high temperature phase of the early universe, there was a time when the temperature of

the universe dropped from about ten billion degrees to a few hundred million degrees. According to the time temperature relationship referred to above, this happened when the universe aged from ~ 1 second to ~ three minutes. It was during this period, that Gamow expected that thermonuclear fusion would make neutrons and protons combine to form the nuclei of the various chemical elements found in the universe.

Gamow and his younger colleagues Ralph Alpher and Robert Herman did the actual calculations based on the nuclear and particle physics data available then. The idea of making all the chemical elements did not, however, work out as there was an unbridgeable barrier at the atomic mass 5. In the mass range 5-8 no stable nuclei exist and so it is not possible to go beyond helium. The heavier nuclei are made more naturally inside stars in the observed quantities. The light nuclear abundances, e.g., of He^4, He^3, H^2, etc., predicted by the above hot big bang nucleosynthesis do broadly match the observed abundances.

The interest in the Gamow approach was revived in the early sixties when it was realized that although the stars are successful in making the heavier nuclei in right amounts, they cannot make helium in sufficient quantities while no scenario is known of making deuterium (H^2) in stars. Thus the abundance of light nuclei in the universe is considered a strong piece of evidence for big bang cosmology.

3. While working on primordial nucleosynthesis Alpher, Herman and Gamow realized that the early universe had a radiation bath of high temperature which would eventually decouple from matter and survive as a relic black body background at low temperature. In 1948, in an article in *Nature*, Alpher and Herman estimated the present temperature at 5K while Gamow estimated somewhat higher values in his later publications. (In fact the standard model *cannot* predict the present background temperature: it is an assumed parameter for the theory)

The present backgound was discovered accidentally - for by the early 1960s astronomers had more or less forgotten this prediction - by Arno Penzias and Robert Wilson in 1965. It was subsequently measured at several wavelengths and the most comprehensive study was made by the COBE satellite in 1980-90. The spectrum is indeed that of a black body of temperature 2.73K. The near-perfect black body spectrum is considered a strong indicator of the relic interpretation of this radiation. This was thus the third prediction that came true.

Weaknesses of the standard model: Despite these advantages, there are problems with the standard model which are numerous and can be briefly highlighted thus.

1. All big bang models start with a spacetime singularity, the so-called big bang. Being a singular event it is such that no physical description of the initial conditions of the universe can be given. In any physical theory, the appearance of a singularity signals a defect. As such, the presence of a big bang itself discredits the theory.

The usual way of proceeding in the standard model is therefore to work backwards: that is, to deduce the state of the universe in the far past depending on what we see of it at present. Thus the temperature of the microwave background is a given quantity at present and used to deduce the physical conditions of the early universe. The present large scale structure is used as the endpoint to settle the initial conditions of its seeds. Thus there is no predictive element in this type of work, as there is no way of independently checking whether such conditions did exist in the past.

2. The interaction of very high energy physics and cosmology is supposed to have taken place when the universe rapidly passed through the GUT-energy $\sim 10^{16}$ GeV. Those epochs were not only beyond the observing capability of any present instrument but were also non-repetative, that is, there was no later epoch when a similar series of events took place, nor will there be one in the future. In science one asks for repeatability of experiments, a criterion not met with in this standard scenario.

3. The big bang nucleosynthesis places an upper limit on baryon density of the universe. So does the observed high degree of homogeneity and isotropy of the microwave background. The standard model on the other hand demands a density 50-100 times this upper limit. So this excess is believed to be made of nonbaryonic dark matter: of particles like massive neutrinos, gravitinos, photinos, axions, etc., none of which have so far been observed. Depending on their masses and interactions in the early universe, these particles are grouped under categories of 'cold' or 'hot' dark matter.

Indeed the observed large scale structure in the universe could not have been explained unless one assumed cold or hot dark matter, or a mixture of both in very finely tuned amounts. Again we find that a number of highly speculative arguments are put together with the sole justification of reproducing the present physical conditions in the universe.

4. The standard model with inflation has age

$$t_0 = \frac{2}{3} H_0^{-1}$$

which lies in the range of $(8 - 10) \times 10^9$ years. This age is far too short compared to the ages of globular clusters which range between $(12 - 15) \times 10^9$ years.

To get round the age problem cosmologists have resurrected the cosmological constant l, which is given the required value to make the age of the universe sufficiently high. Again this calculation is devoid of predictive power since there is no apriori rationale as to why the λ should have that chosen value.

5. There are problems with the cosmological constant too. If it is assumed that the present cosmological constant is the relic of the inflationary era, then one has to assume that after the inflation was over and the original cosmological constant nearly disappeared, there was a remnant of the order 10^{-108} left behind for the present epoch; which is indeed a highly improbable and superfine-tuned assumption.

Moreover, even if we assume that the relic value of this constant was just the right amount to explain the present large scale features of the universe, there are limits upto which it can be allowed. For example, the frequency of gravitationally lensed sources sets an upper limit on this constant

$$\lambda \leq 2H_0^2 / c^2.$$

Further, if we allow too large a l, we end up getting an accelerating universe. This leads to a negaitive deceleration parameter for the expansion of the universe, which is also ruled out by the present observetions of the distant galaxies.

I am giving these reasons to indicate why the standard big bang model is highly constrained observationally, besides having conceptual difficulties of a fundamental nature. In science it is customary to keep any theory, howsoever successful it may be, on probation for possible rejection or replacement by a better and more complete theory as more constraining observations become available. I feel that the standard model in cosmology has now reached a stage where thinking of alternative ideas to replace it with may not be out of place.

It should be emphasized, that the proposal of a new alternative does not presuppose that the standard theory is rejected. Rather, the proposal is to be looked upon as providing a healthy competition so that theorists and observers raise their criteria for the survival of a theory to more sophisticated and demanding levels, which works towards the improvement of the subject as a whole.

It is also important that the alternative that may be proposed should (i) be expected to do at least as well as the standard model, (ii) make observable predictions to distinguish it from the standard model as well as to demonstrate its agreement with the real universe.

During 1948-65, the steady state cosmology had played such a role vis-a-vis the standard model. Proposed by Hermann Bondi, Tommy Gold and Fred Hoyle in 1948, this cosmology had stimulated the cosmological observational and theoretical fields by playing the role of an alternative. The discovery of the microwavebackground and the findings of light nuclei like deuterium and helium in quantities not possible to be produced in stars, created difficulties for this theory while providing ammunition to the big bang cosmology. During the last 25 years, however, there has been no comparable new evidence of that calibre (COBE notwithstanding) to support the big bang picture which, as stated above has become more and more speculative. Thus the situation for considering an alternative is now ripe.

In the rest of this article we will describe such an alternative, the Quasi-Steady State Cosmology, or QSSC in brief.

The Quasi-Steady State Cosmology: The basic features

In 1993, Fred Hoyle, Geoffrey Burbidge and the author proposed an alternative cosmology which was a variation of the steady state cosmology. The basic idea behind this model is as follows.

The Formal Structure: Since any cosmological theory must explain how matter (and radiation) appeared in the universe, there shouls be a formalism specifying this in the action principle defining the theory. In the QSSC, the action principle is that of the Machian theory of inertia and gravitation which was first proposed by F. Hoyle and the author in 1964. In this theory the inertia of a particle is supposed to arise from a long range scalar interaction of that particle with all other particles in the universe. Explicit note of matter creation (and annihilation) is taken through the possibility that the typical worldline can have a beginning (and an end). The interaction is conformally invariant, that it, it preserves its basic form if all lengths are arbitrarily scaled at different points of space and time. The theory therefore allows for particle mass to vary in space and time.

The mathematical equations of this theory are similar to but more genral than the field equations of general relativity. They can be simplified, however, in the specific conformal frame in which all particle masses are constant with space and time. In this case the theory also tells us that the creation of matter is described by a scalar field which is related to the original mass interaction. This field has negative energy and pressure and it therefore allows matter to be created without the violation of the law of conservation of energy and momentum.

The constant mass frame also leads to another term similar to the cosmological constant l of general relativity. The constant is, however, negative, that is, it leads to a cosmic long range force of attraction.

Mini-Creation Events: How does matter appear in the universe? The creation condition specified by the action principle requires a minimum threshold for the intensity of the scalar creation field to create the basic particle, the so-called Planck particle whose mass is

$$m_p = \sqrt{\frac{3c\hbar}{4\pi G}} .$$

This particle has a mass ~ 10^{-5} gram, which is very large compared to the typical baryonic mass. To create such a heavy particle therefore, the average intensity of the creation field has to be high. The general background level of the field is inadequate for this purpose. However, it can be raised to the required level in the neighbourhood of a massive compact object. For, the strong gravity of such an environment raises the energy level of the scalar field. An analogy may help: when we drop a particle form rest into a well, it acquires a high velocity and hence large kinetic energy as it falls deep into the well.

When creation does occur, the strength of the scalar field is further increased (because, when you take a positive amount from a negative reservoir, the negativity of the latter increases). So the creation is further facilitated. The process is not, however, unstable of the runaway kind. For, the gravitational equations relate the feedback of a large accumulation of negative energy and negative stresses to the geometry of the ambient spacetime. The space expands and the created particles are thrown outwards. This is nothing but an explosive creation of particles, but without any spacetime singularity.

Such an event is called a mini-creation event (MCE) and the theory tells us that wherever there is concentration of matter in compact objects with strong gravitational fields, there is an MCE. What happens if there are a lot of MCEs distributed all over space?

Because space expands near a typical MCE, the combined effect of several such MCEs in space is to generate a large scale expansion of space. This is how the universe as a whole expands.

Cosmological Solutions: The field equations of the theory can be solved explicitly in certain simple cases. If we assume that the universe is homogeneous and isotropic, that is it has the same appearance at all points and it looks the same in all directions, then we have the following picture.

In a strict steady state, there will be an exact balance between the frequency of the MCEs and the expansion of the universe. As the MCEs produce more and more matter, and expand the space, the strength of the creation field is maintained at a steady level by two opposing phenomena. The creation activity increases the density of the creation field energy while the expansion of the universe dilutes and decreases it.

The assumption of strict steady state is, however, unrealistic: rather, we expect the creation activity to peak at some epochs which causes the expansion of the universe to be accelerated. However, with more rapid expansion the average background of the creation field drops and it becomes harder for creation centres to operate. Many MCEs therefore cease to function. This reduces the outward push on space and slows down the expansion. The l term, which grows with distance now steps in and causes the universe to contract. As the universe contracts, the intensity level of the creation field increases and several creation centres, which were hitherto lying dormant start operating, thereby raising the frequency of the MCEs. The universe starts expanding again. Thus a complete cycle of expansion followed by contraction takes place around the steady state solution. Therefore the universe is in quasi-steady state.

The spacetime geometry of this model is described by the well known Robertson-Walker line element used in standard cosmology. In the simplest solution, the spatial geometry is assumed to be flat. The scale factor for such a composite model with oscillations of short period Q superposed on an exponential expansion of long term P, is given by

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

where $\tau(t)$ is a function of t with the property that for most part of the oscillation, τ is almost linear in t, being significantly different only during short time spans near the maxima and minima of S. The period of S in τ is 2p, while in t it is Q, which is fixed by the field equations. In general, $P >> Q$.

The steady state requirement here says that, although the universe evolves during a typical cycle, each cycle as a whole will be the same as the preceding one. In other words, all physical conditions in one cycle will be the same as in any other cycle. For convenience we will assume that a cycle begins at the maximum density epoch and ends at the next maximum density epoch when the next cycle begins. This process is endless, and without a beginning.

The basic QSSC model has four parameters: Q,P,h and t_0, the present epoch in a typical cycle. They are interrelated by field equations and can be fixed by referring to some observable features of the universe.

Existing Observational Tests

We now come to some key observational tests for the QSSC, tests which it must satisfy.

1. The discrete source studies of the universe include (i) the m - z relation, that is, the variation of redshift with apparent faintness of the galaxies, (ii) the counts of radio sources and galaxies, (iii) the θ-z relation showing how the angular size varies with redshift and (iv) the largest redshift seen.

Tests (i), (ii) and (iv) help us fix the optimum model parameters while the test (iii) can then check if the model fares well with these parameters. The recent data on the angular sizes of the ultracompact (VLBI) components of large redshift radio sources do support the predictions of the theory rather well, as shown recently by Shyamal Banerjee and the author.

The parameters that seem to provide a reasonable fit to these data are as follows:

$P = 20Q$, $Q = 4.4\text{x}10^{10}$ years, $h = 0.8$, $t_0 = 0.7Q$.

Once these parameters are fixed the model must satisfy any additional tests without any further adjustments.

2. How does the QSSC explain abundances of light nuclei? This may at first sight seem an insurmountable difficulty, as the maximum redshift in the present cycle is $\leq \sim 6$, indicating that the universe did not have a high temperature phase in the past as in the standard model to trigger and sustain nucleosynthesis.

The solution to the difficulty is through the primary creation process. Recall that the particle created is the Planck particle which has a very short lifetime $\sim 10^{-43}$ second. This particle decays through a series of high energy processes, following the standard model of particle physics, ultimately ending in the baryon octet as well as pions, leptons, radiation, etc. At energies >> 1GeV, the octet will have an equipartition of particles. Of the eight species, six are short-lived and decay to protons whereas the longer lived proton and neutron combine into the helium nuclei. Therefore we expect about twentyfive percent of mass to end up as helium. A more careful calculation taking into account radiation and other particles, the creation of other light nuclei and some metals, yields the helium mass fraction $Y = 0.22\text{-}0.23$.

The theoretical abundances of deuterium and other light nuclei are very well in conformity with the actual abundances. A difference from the big bang nucleosynthesis is that the deuterium mass fraction does not critically depend on the present baryon density as in the big bang model. This has implications for the dark matter in the universe.

3. The microwave background in this model is obtained as follows. Each cycle is of long enough duration to have formed and evolved most stars through their full life cycles. What happens to their light? Imagine that all the starlight produced in a given cycle is thermalized. As the universe has no beginning and no end, the starlight from the previous cycles will have produced a background to which this will be added. Since radiation density u falls as α S-4 due to expansion, with the rate of long term expansion

going as exp(t/P), the depletion produced in the pool at the end of a cycle of duration Q will be by a fraction $\Delta u = 4Qu/P$. In a steady state, this must be made up by the thermalised starlight of that cycle.

From the stellar activity observed at present, one can estimate how much relic starlight energy density will be available at the end of the cycle. Suppose it is $\in$. Then the steady state requirement will be:

$$4Qu/P = \in$$

The energy density at the start of the cycle being thus known, we can calculate its thermalized temperature T by the usual formula. The present temperature will then be

$$T_0 = T(1 + z_{max})^{-1}$$

where z_{max} is the maximum redshift at the start of the present cycle as seen from today's epoch.

Calculations based on the above theory yield a present day temperature of the microwave background as ~ 2.7K. This is indeed a triumph for the theory, for , as we mentioned earlier, the big bang cosmology cannot predict the present temperature.

How is the starlight thermalized? This is achieved by the absorption and reemission by intergalactic dust in the form of metallic whiskers. Such whiskers form when metals are created in supernovae as well as in the MCEs, ejected in vapour form and then condense in cooler regions. Considerable theoretical work has been carried out by F. Hoyle and N.C. Wickramasinghe on this topic. Experimental work also shows that metallic vapours condense not as spherical particles but as whiskers upto ~ 1mm long and ~ 10^{-6} cm in cross sectional diameter. These have the right kind of extinction properties to thermalize the radiation. Because of these whiskers, the universe is opaque to the millimetre waves, reasonably transparent to the visual waves and certainly more transparent to radio waves.

The radiation, having been thermalized for several cycles, will therefore show a spectrum very close to the Planckian spectrum. There may be a departure from the Planckian form at wavelengths longer than ~ 20cm. So far this is quite consistent with observations of the MBR. the inhomogeneities of the type first found by COBE, arise (i) from the residual inhomogeneities of whisker distribution after it has been pushed around by radiation pressure gradients and (ii) from the inhomogeneities of local microwave sources. The expected fluctuation in temperature &T/T is around a few times 10^{-6}.

4. The universe, being without a beginning, has no age problem. Thus ages as old as 15-18x10^9 years of stars or galaxies can easily be accommodated in the model. There are indeed further predictions in this regard, of this cosmology that we will highlight in the next section.

Future Work

We end this article by discussing the lines of future research in the QSSC. The work so far has indicated that the cosmology has enough prima facie strength to face the observational constraints and it avoids the theoretical difficulties of the standard model discussed in Section 2. Some productive lines of future investigation which help distinguish this cosmology from the standard cosmology are as follows:

1. As we extend our surveys of discrete sources farther away from us we should encounter higher and higher redshifts in standard cosmology. In the QSSC, on the other hand, beyond z_{max}, the redshifts begin to decline for farther objects and we may even encounter objects with small blueshifts ($-z \leq 0.1$, say). This may require spectroscopy of galaxies fainter than 26^m.

2. We expect to see very old stars just off the main sequence in the QSSC. These are stars with mass less than or equal to around half a solar mass. Such stars would have been born in the last cycle and may be as old as $40\text{-}50 \times 10^9$ years old. If such stars (preferably in a cluster) were found, they would be impossible to accommodate in the standard cosmology.

3. Neither the deuterium abundance nor the temperature fluctuation of the MBR present the QSSC with an upper bound on the baryonic mass density. Therefore, if evidence were found for the baryonic mass density at a level significantly higher than the big bang limit, it would be a point in favour of the QSSC. In this context, the MACHO type surveys will also be helpful in identifying dark low-mass baryonic objects such as burnt out stars, large planets, brown dwarfs, etc.

4. In standard cosmology, the formation of large scale structure in the universe is proving to be a difficult problem to tackle, as indicated earlier. A different approach indicated by the QSSC is already proving successful. In this approach, the creation of matter around MCEs is the key process which generates new massive objects near existing ones. Computer simulations by Ali Nayeryi already show that a random distribution of new generation objects near older MCEs produces a void-supercluster distribution very close to what is observed. More sophisticated simulations together with gravitational clustering would be needed to follow up this work.

Conclusion

These brief but wide ranging ideas give us an indication that much is possible in developing the QSSC as an alternative cosmology. Such a competing rival to the standard model will help focus on a few well defined discriminating tests, which in turn will make the cosmological observational scene more stimulating. On the theoretical side, more detailed work on structure formation is needed to face what is perhaps the strongest challenge in cosmology.

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