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The quasi-steady-state cosmology

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Abstract

This paper outlines an alternative cosmology called the *quasi-steady-state cosmology* (QSSC) which was proposed in 1993 as a rival to the standard big bang cosmology (SBBC). The motivation for an alternative cosmology is introduced by first discussing some of the weak points of the SBBC. The theoretical framework and observational tests of the QSSC are next described. Finally some tests which can distinguish between the SBBC and the QSSC are briefly mentioned.
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1. Introduction

Modern theoretical cosmology began in 1917, with Einstein's model of the universe, in which the universe was assumed to be homogeneous and isotropic and *also static* [11]. The general belief in a static universe in which the galaxies etc., are at rest was quite strong so that when a few years later Alexander Friedman [12,13] proposed expanding models of the cosmos, they were largely ignored as mathematical curiosities. However, the first significant observational result in cosmology came in 1929 when Edwin Hubble [22] announced the velocity–distance relation for galaxies. The apparent universality of Hubble's law led people to a paradigm-shift that the universe is not static but *expanding*. And the Friedmann models, which had also been independently discovered by Abbe Lemaitre [23], became the recognized models for the universe. As Lemaitre had observed, these models appeared to start from the state of infinite density, which he interpreted to mean a *dense primeval atom*. In modern jargon this is identified with the state of *big bang*. It signifies a singular epoch when all the matter and energy present in the universe today, appeared in violation of the law of conservation of matter and energy.

In the late 1940s and the early 1950s, George Gamow, Ralph Alpher, Robert Herman [1,14] and others explored this supposed dense primordial state. They showed that the early universe was dominated by high temperature radiation and other subatomic particles moving at near-light speeds. They felt that the physical conditions during a short era were ideal for nuclear fusion making all the chemical elements from protons and neutrons. However, they could not proceed beyond essentially ^{4}He, because of the absence of stable nuclei at mass numbers 5 and 8. But as Alpher and Herman [1] pointed out, *if* there had been such an early ultra-dense stage, the universe might well contain an expanding cloud of primordial radiation that would preserve its blackbody form as the universe evolved. The microwave background observed today is widely believed to be that relic radiation.

In the 1940s, however, another new idea challenging this hot big bang picture appeared on the scene, when three British astrophysicists, Bondi and Gold [8] as well as Fred Hoyle [15], proposed the *steady-state model*. It not only assumed the universe to be homogeneous and isotropic in space, but also unchanging in time. Bondi and Gold proposed the 'perfect cosmological principle (PCP)' that essentially said this. It served as a basic principle that enabled the astronomer to deduce all the basic properties of the universe by simply observing the local region. Thus one could argue that there was no big bang, no hot phase; in fact the universe was essentially without a beginning and without an end. *It, however, steadily expanded*, thus creating new volumes of space. In order to maintain a constant density as required by the PCP, these volumes had to be filled up with new matter that was continually created. In Hoyle's version, the phenomenon of creation of matter was considered fundamental in determining the dynamical and other properties of

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the universe. Hoyle in fact proposed a slight modification of Einstein's general relativity so as to account for matter creation out of a negative energy reservoir of energy. As more and more matter got created, energy conservation required the reservoir to become more and more negative. However, negative energy led to repulsion and expansion of space, as per the Einstein equations and because of expansion, the energy density of this reservoir remained steady.

Thus in the steady-state theory there was no mystical event like the big bang and no sudden appearance of all the matter into the universe. Instead there was a steady expansion supported by a continuous creation of matter. In Hoyle's version this matter creation was consistent with the law of conservation of matter and energy. In 1948, the estimates of the age of the big bang universe showed it to be very small (of the order of 2×10^9 yrs), smaller than the geological age of the Earth ($\sim 4.6 \times 10^9$ yrs). Thus there was a manifest conflict between the geological time scales and the big bang cosmological ones, which got less severe as later measurements reduced the value of Hubble's constant by a factor ranging between 5 and 10. Even today, however, the conflict remains in the sense that estimates of some stellar ages are marginally higher than the age of the universe. We will return to this evidence later.

Nevertheless, during the 1950s and the early 1960s the debate between the big bang and steady-state theories continued unabated. Two events in the mid-1960s eventually swung the argument in favour of the big bang cosmology. One was the realization that the observed abundances of light nuclei in the universe required their manufacture in a very hot dense stage. The possibility of making these in the observed quantities in the interiors of stars was discounted. The other was the observation of the microwave background radiation which was quickly interpreted as the relic of the early hot era. Thus the big bang model acquired the status of the 'standard model' of the universe.

After these initial successes of the mid-1960s, work in the standard big bang cosmology (SBBC) picked up momentum. However, despite most cosmological talent working on this idea, the last three decades have not been so spectacular in terms of achievements. Rather, going into details has brought out some crucial weaknesses of the SBBC, which we shall discuss next.

Because of these it is not altogether out of place to consider an alternative approach to cosmology which was proposed by Fred Hoyle et al. [18]. The rest of this paper is about this alternative cosmology which its originators called the 'quasi-steady-state cosmology (QSSC)'.

2. The standard cosmological model: some critical issues

Let us begin by examining the above two lines of evidence that are claimed to be the strongest in favour of the standard model, namely, the origin of light nuclei and the microwave background.

2.1. The origin of light nuclei

In the mid-sixties, Wagoner et al. [35] repeated a calculation originally reported by Gamow, Alpher and Herman. They concluded that a synthesis of the light elements in the early hot universe yielded abundances of deuterium, ^{3}He, ^{4}He, and ^{7}Li that were in satisfactory agreement with astrophysical observations *provided* the average cosmological density ρ (in g/cm^3) of baryonic matter was related to the radiation temperature T (in Kelvin) by a finely tuned relation:

$$\rho = 10^{-32}\ T^3. \tag{1}$$

A finely tuned relation can be an asset to a theory, if observations bear it out. Or it may prove to be a liability if it *does not* conform with them. Cosmological theory requires this ρ–T relationship between density and temperature to be maintained throughout the expansion of the universe from its early hot state. So, putting in the measured value of the present background temperature, $T = 2.73$ K, yields about 2×10^{-31} g cm^{-3} for the present-day average cosmological density. For a comparison, the standard model predicts the present density of the universe to be close to $2 \times 10^{-29} h_0^2$ g cm^{-3} where the present value of Hubble's constant is $H_0 = 100 h_0$ km s^{-1} Mpc^{-1}. This density is sometimes referred to as the *closure density*: models more dense than this are closed in the topological sense, while those with less density are open. Thus, with the value currently favoured by observations, $h_0 \cong 0.6$, the density given by (1) is $\sim$2.8% of the closure density, whereas an SBBC with an inflationary phase would predict the density equal to the closure density.

Although the density given by (1) was almost two orders of magnitude less than the closure density, it agreed with galactic astronomer Jan Oort's estimate for the cosmic average density of observable material. The higher "closure" value given by the standard cosmological theory, is rationalized by assuming the existence of the (as yet) hypothetical *nonbaryonic* matter. What it actually is, cannot be tested as yet, and theoretically favoured species has changed its identity over the years from massive neutrinos to esoteric "cold-dark matter" particles or WIMPs (weakly interacting massive particles), perhaps with some remaining admixture of massive neutrinos. Evidently, it is not reassuring that this

line of reasoning from the 1960s is still the best available in favour of big bang cosmology, despite the continuing failure of attempts to identify the required nonbaryonic matter.

2.2. The relic radiation

A strong point of the hot universe theory is always claimed to be its prediction of the Planckian spectrum of the radiation, a prediction that was amply confirmed in 1990 by the COBE-team [25]. However, the weakness of the argument lies in its inability to predict the *actual temperature* of the radiation at the present epoch. Guesstimates have ranged from 5 to 50 K [4]. On precisely this issue, the standard-cosmology argument on relic radiation can be countered by a still more precise calculation with a very different implication. We know that ^{4}He is synthesized from hydrogen in stars with an energy yield of about 6×10^{18} ergs for each gram of helium, the energy being radiated by the stars to produce a radiation background. If all of the ^{4}He in the universe has been produced in this way (the observed abundance is about one ^{4}He for every 12 hydrogen atoms), then the accompanying radiation background should have an energy density of

$$u = 4.37 \times 10^{-13}\ \mathrm{erg\,cm^{-3}}. \tag{2}$$

That is quite close to the observed energy density of the microwave background, namely 4.18×10^{-13} erg cm^{-3}.

Either this agreement is coincidental, or we must conclude that the ^{4}He was created, not by big bang nucleosynthesis, but rather by hydrogen burning inside stars and that the radiation background from stars has become subsequently thermalized into the far infrared (as discussed in Section 3).

2.3. Other problems with the standard model

We turn now to further problems associated with the so-called standard model. If negative values of the energy density are prohibited, one can argue that the observed expansion of the universe requires not only that the universe was more compressed in the past, but additionally that it was also expanding in the past. If we denote the time dependence of the linear scale factor of the universe by $S(t)$, general relativity tells us that the scale factor has always been increasing in the past and, as we look back in time, we see the universe become more and more compressed at earlier and earlier times. Ultimately to what initial state? Mathematical analysis inevitably leads to a state of 'singularity', i.e., of infinite density, temperature and curvature, provided one uses conventional physics. However, what was physics like in the early universe?

In attempts to answer this question, it is accepted that if we follow the evolution of the universe backward in time, particle energies increase up to values in the TeV range, and then, by speculation, all the way to infinity at the big bang singularity. Up to 10^{15} GeV, symmetry arguments are invoked and the theory departs increasingly from known physics, until ultimately the energy source of the universe is put in as an initial condition, as are other physical conditions like the fluctuations of matter density that became enhanced later to form galaxies in an otherwise homogeneous universe. Because the intitial conditions are beyond the present observer's ability to observe and verify, and because the particle physics has remained untested at energies of the order 10^{15} GeV, we are completely at the mercy of speculations! More so, as the primordial conditions are never repeated at any later stage, which means that we are in fact not able to satisfy the 'repeated testability' criterion of a physical theory.

Weinberg [36] has highlighted the so-called *cosmological constant problem*. If we assume that inflation took place in the very early universe, it was driven by a cosmological constant term Λ, arising from the vacuum. If today we wish to claim a relic Λ, then we have to assume that it is an extremely tiny ($\sim 10^{-108}$) fraction of the original value at the time of inflation. Indeed in 1917, Einstein had modified his original equations of general relativity to accommodate a cosmological term of this order, so as to obtain his static model. However, if one wishes to argue that such a force is indeed present as a relic of the early inflationary era, then the following question arises. Why was the relic value so finely tuned to what is claimed to be its observationally estimated value today? This question is sought to be answered with theoretical ideas that go under the name of 'quintessence'. It is too early to judge these efforts; but it cannot be denied that they introduce an 'extra epicycle' in the standard cosmology. But does standard cosmology require a cosmological constant which had been abandoned by Einstein in the 1930s as being an unncessary burden on general relativity?

Unfortunately standard cosmology does seem to require the existence of a cosmological constant of this order today, for two reasons. Firstly, the age of the standard model without Λ and with $\Omega = 1$ is too small to accommodate ages of some of the oldest stars in globular clusters. Secondly, the redshift magnitude relation using Type IA supernovae seems to require a nonzero Λ.

In a recent review Narlikar and Padmanabhan [29] have pointed out that the SBBC in fact has *seven* parameters to describe it: the Hubble constant, the baryonic density parameter, the dark matter density parameter, the cosmological constant, the relic radiation temperature as well as the amplitude and index of the initial mass fluctuation spectrum. These latter two parameters are needed to explain the large scale structure observed today.

These and some other unsatisfactory features (for a detailed discussion see [2]) led Hoyle et al. [18] to take a fresh look at cosmology and try a new approach which they named the 'QSSC'.

3. The Quasi-steady-state cosmology

The theoretical structure and relationship to observations of this cosmology are summarized below.

(1) The cosmology is based on the Machian theory of gravitation first proposed by Hoyle and Narlikar [16,17]. The HN theory starts with the premise that inertial mass of any particle is determined by the surrounding universe. In field theoretic language, the inertia is a scalar field whose behaviour is determined by an action principle. As shown by Hoyle et al. [20], the theory permits broken particle world lines, i.e., creation and destruction of matter. In the cosmological approximation of a well-filled universe, the field equations become:

$$R_{ik} - \frac{1}{2}g_{ik}R + \lambda g_{ik} = -\frac{8\pi G}{c^4}\left[T_{ik} - f\left(C_iC_k - \frac{1}{4}g_{ik}C^lC_l\right)\right], \tag{3}$$

where C is the scalar field representing the inertial effect associated with the creation of a new particle, and a consequence of Mach's principle is that the constants in these equations can be related to the fundamental constants of microphysics and the large scale features of the universe. Thus we have

$$G = \frac{3\hbar c}{4\pi m_{\mathrm{P}}^2}, \quad \lambda = -3\left[\frac{m_{\mathrm{P}}}{\mathscr{N}}\right]^2, \quad f = \frac{2}{3}\hbar c. \tag{4}$$

Here m_{P} is the mass of the basic particle created, and $\mathscr{N}$ the number of such particles in the observable universe. From the above it is easy to identify m_{P} with the Planck mass, which makes $\mathscr{N}$ of order 10^{60} and λ of order 10^{-56} cm^{-2}. Notice that its sign is negative, i.e., it is an *attractive* rather than a repulsive force. The coupling constant f is positive, thus requiring the C-field stress and energy to act repulsively on matter and space because of the explicit minus sign in the stress tensor. It is assumed that the creation of a particle of mass m_{P} is possible provided a 'threshold' is attained by the ambient C-field, namely, $C_lC^l = m_{\mathrm{P}}^2$. In such cases, we may have situations with $T^{ik}_{;k} \neq 0$, although the divergence of the overall right hand side is zero.

(2) The cosmological models in this theory are driven by the creation process, and it is argued that the creation does not occur uniformly everywhere, but *preferentially* near massive objects collapsed close to the state of a black hole. This is because the gravitational field in the neighbourhood of such an object is high and permits the local value of C_lC^l to rise high enough to reach the creation threshold. The Planck particle so created is assumed to be unstable, however, and decays within a time scale of order 10^{-43} s, into baryons, leptons, pions, etc. along with a release of substantial amount of energy. The creation of matter is compensated by the creation of the C-field, and as the strength of the field rises, its repulsive effect makes the space expand rapidly (as in the inflationary scenario), thus causing an explosive ejection of matter and energy.

In a typical minicreation event like the above, the central object itself may break up as its gravitational binding is loosened by the growth of the negatively coupled C-field. Thus it may also happen that the central object may eject a coherent piece along the line of least resistance. The QSSC authors argue that some of the 'anomalous redshift' cases [3,26] can be explained by this phenomenon.

(3) The cosmological solutions are driven by the minicreation events, each of which produce local expansions of space. The averaged effect of a large number of such events over a cosmological volume can be approximated by a homogeneous and isotropic solution of the field equations. As in the SC, the Robertson–Walker line element can be used to describe such a spacetime. The work of Sachs et al. [33] has shown that the generic solution for all three cases $k = +1, 0, -1$, is one obtained by a long term steady expansion interspersed with short term oscillations. For example, the scale factor for $k = 0$ is given by

$$S(t) = \exp(t/P)[1 + \eta\cos\tau(t)], \tag{5}$$

where $0 < \eta < 1$, so that S oscillates between two finite values and $\tau(t)$ is almost like t during most of the oscillatory cycle, differing from it mostly during the stage when S is close to the minimum value. The period of oscillation Q is

small compared to P. The QSSC is therefore characterized by the following parameters: P, Q, η and $z_{\max}$, the maximum redshift seen by the present observer in the current cycle. Sachs et al. [33] took $P = 20Q$, $Q = 4.4 \times 10^{10}$ yrs, $\eta = 0.8$, $z_{\max} = 5$, as an indicative set of values. The QSSC workers have argued that the cosmology is not tightly constrained around these values, by the various cosmological tests.

(4) How is the microwave background produced in this model? The QSSC oscillations are finite with the maximum redshift observable in the present cycle at ~5–6. Thus each cycle is matter-dominated. The radiation background is, however, maintained from one cycle to next. If there were no further contribution to the radiation background, then from the minimum scale phase of one cycle to next, its energy density is expected to fall by a factor $\exp(-4Q/P)$. This drop is, however, made up by the thermalization of starlight produced during the cycle. This if ϵ is the energy density of starlight generated in a cycle and $u_{\max}$ is the energy density of the CMB at the start of a cycle, then $\epsilon \cong 4u_{\max}Q/P$. If the cycle minimum occurred at redshift $z_{\max}$, then the present CMB energy density would be $P\epsilon/4Q(1+z_{\max})^4$. Substituting the values of ϵ, P, $z_{\max}$ and Q we can estimate the present-day energy density of CMB and the result agrees well with the observed value of $\sim 4 \times 10^{-13}$ erg cm^{-3} corresponding to temperature ~2.7 K.

Ordinarily, relic starlight over several cycles would end up in an infrared background. However, it gets degraded by frequent scatterings, absorption and reemission by particles in the intergalactic medium. In fact it will lead to its eventual thermalization. Consider the following scenario. The cooling of metallic vapours like iron and carbon produces whisker-like particles of lengths ~0.5–1.0 mm. which convert optical radiation into millimetre one. Such whiskers typically form in the neighbourhood of supernovae (which eject metals), and subsequently pushed out of the galaxy through pressures of shock waves. It can be shown that a density of $\sim 10^{-35}$ g cm^{-3} of such whiskers close to the minimum of the oscillatory phase would suffice for thermalization of starlight. Narlikar et al. [28] have discussed evidence for such whiskers in different astrophysical settings.

While the thermalized radiation from previous cycles will be very smoothly distributed, a tiny fraction ($\sim 10^{-5}$) will reflect anisotropies on the scales of rich clusters of galaxies in the present cycle. The angular scales for this anisotropy will be of the order $\sim 1/100$, $-1/250$ for superclusters corresponding to l-values ~100–200.

(5) In a recent paper Burbidge and Hoyle [9] have argued that a case may be made for *all* isotopes to have been synthesized in stars, including the light ones generally assumed to be of primordial origin. Of the light nuclei, the longer time scales of the QSSC allow sufficient ^{4}He to be produced in stars, sufficient for all of its observed abundance to be of stellar origin. Why then do not we see a high metal content also? The reason is that in a long time scale cosmology, the helium comes from low mass stars which do not reach the stage of producing metals. (In the shorter time scales of SC, the metals come from high mass stars.) Burbidge and Hoyle (op. cit.) have pointed out that spallation reactions of high energy cosmic ray protons on ^{12}C and ^{16}O nuclei can produce the isotopes ^{6}Li, ^{9}Be, ^{10}B and ^{11}B. Modern work shows that high energy C and O can also bombard protons and α-particles to produce these nuclei (see for example, [34]). Stellar winds from massive stars and ejections from supernovae can produce such high energy nuclei. Concerning ^{7}Li, apart from the HBBC nucleosynthesis, process of galactic production has also been suggested by the recent observations of stellar abundances [5,24,32].

Burbidge and Hoyle have also argued that ^{3}He is produced in large quantities in dwarf stars. There are several other stars which show that most of the helium in their atmosphere is in the form of ^{3}He. A longer time scale for stellar processing is capable of yielding an ^{3}He/H ratio $\approx 2 \times 10^{-5}$ as observed. Likewise there is growing evidence of processes that can generate deuterium in stars, e.g. in stellar flares and given a time scale of the order of 10^{11} yrs, it would not be difficult to enrich the interstellar gas with D to the extent observed. More measurements of the D/H ratio will throw light on the process of deuterium production.

Indeed, if one can show that all nuclear abundances can be explained as of stellar origin along the lines of BBFH [10] and the microwave background is seen as thermalized starlight, then a major motivation for a hot big bang disappears. The link with very high energy particle physics including ideas on grand unification and supersymmetry are then seen to apply to a Planck fireball produced in a typical minicreation event, rather than to a singular big bang. This has the added advantage that unlike the big bang which only happened once, Planck fireballs are repetative events, thus providing the physicists with cosmic high energy laboratories in the true sense.

(6) The QSSC has been applied to the redshift-magnitude relation obtained by using Type IA supernovae. Banerjee et al. [7], have reexamined the problem in the context of the QSSC for the data used by Perlmutter et al. [31] for fitting the SC models, with or without the cosmological constant. As we have seen, the QSSC requires intergalactic dust in the form of metallic whiskers. This whisker population acts to produce further absorption in the light from distant galaxies and supernovae therein. Taking this effect into account Banerjee et al. (op. cit.) fitted the QSSC model to data by taking the dust density as a free parameter. The optimized fit turns out to be better than that achieved by the best fit SC model including the cosmological constant as a free parameter. And the optimum whisker density turns out to be in the right range for thermalization of starlight into the microwave background.

Earlier Banerjee and Narlikar [6] had applied the QSSC model to the angular size redshift data on ultra-compact radio sources to show a good fit. These authors, however, find that although flat ($k = 0$) models give an acceptable fit the models with $k = -1$ give a better fit.

Hoyle et al. [19,21] showed how a mixed population of strong and weak radio sources in the QSSC, can generate the observed features of the number-count curve, without ad hoc evolutionary functions (commonly invoked in a typical parameter—fitting exercise of the SC).

4. The minicreation events, dark matter and active nuclei

During the period 1958–1964, the distinguished Armenian astrophysicist Viktor Ambartsumian first developed the idea that many groups and clusters of galaxies are systems of positive total energy—that is to say, expanding systems not gravitationally bound—and that many small galaxies were formed in and ejected from the nuclei of larger systems. He also accepted the evidence of explosive events in radio sources and Seyfert galaxies. In the 1960s, when quasi-stellar objects with large redshifts were being identified in increasing numbers, it was realized that they are also highly energetic objects closely related to explosive events in galaxies.

How are we to understand such great outpourings of matter and energy? As far as the associations and clusters of galaxies are concerned, most theorists, unlike Ambartsumian, have simply not been prepared to accept the observations at face value. For many years, they have argued that the proto-galaxies and galaxies were formed early in the history of the universe. From that point of view, it is impossible to believe that many galaxies are less than a billion years old, which must be the case if galaxies are, even now, being formed and ejected in expanding associations. It is generally agreed that, in such groups and clusters, the kinetic energy of the visible objects is much greater than their potential energy. The conventional approach is to assume that such groupings are indeed gravitationally bound—by large quantities of unseen "dark matter". This conjecture was already put forward for some of the great clusters of galaxies by Fritz Zwicky in the 1930s (see for example, [37]). In the 1970s, the view that the masses of systems of galaxies on all scales are proportional to their sizes became widely believed, but it was not stressed that this result is only obtained by assuming that they are bound and therefore obey the virial condition for which there is no other evidence.

The QSSC suggests that these open systems are in fact the remnants of minicreation events and that their excess kinetic energy is the result of their explosive origin. As we shall see in the following section, the minicreation events play a key role in forming the large scale structure observed in the universe today.

At the same time, there is considerable evidence—from the flat rotation curves of spiral galaxies—for the existence of dark matter in them. This dark matter could very well be stars of previous cycles which are burnt out and devoid of any radiation. They could also be white dwarfs of very large ages of the kind not possible in the relatively limited lifespan of the standard model.

What about radio sources, active galactic nuclei and quasi-stellar objects? It is generally accepted that they all release very large amounts of energy from dense regions with dimensions no larger than our solar system. It has been clear since the early 1960s that there are only two possibilities: This energy is either gravitational in origin, or it is released in creation processes. Conservatively, the total energy release in powerful sources is at least $10^5 M \odot c^2$. In the radio sources, much of this energy resides in highly relativistic particles.

To get such enormous energy releases in gravitational collapse it is necessary to consider processes very close to the Schwarzschild radius, where it would be very difficult to get the energy out. Even if the efficiency of the initial process is as high as a few percent, the efficiency with which the gravitational energy is then converted through several stages into relativistic particles and magnetic flux would be very small. Despite these difficulties, the standard model explaining active galacitc nuclei asserts that, in all such situations, there is a massive black hole at the centre of the galaxy, surrounded by an accretion disk, and that all of the observed energy, emitted in whatever form, is gravitational in origin. All of it, we are told, arises from matter falling into the disk and then into the black hole. But this type of model cannot convincingly explain the many observed phenomena, largely because the efficiency with which gravitational energy can be transformed into relativistic particles and photons is so small.

It is much more likely that, in active galactic nuclei, we are seeing the creation of mass and energy as proposed in the QSSC. Massive near-black holes are undoubtedly present in the centres of galaxies. But when they are detected, the galaxy is typically *not* active. The important feature is probably the quasi-steady-state creation process, which can take place in the presence of a large mass concentration.

Finally, in the mid-1970s Narlikar et al. [27] had discussed the role of white holes in explaining gamma-ray bursts. The idea has similarities with the minicreation events of the QSSC wherein a rapid explosion produces high energy quanta in short periods. These may very well be relevant to the recent more systematic studies of gamma-ray burst events.

5. Large scale structure

The minicreation centres act as nuclei for large scale structure. Nayeri et al. [30] simulated a toy model on a computer to see how the real process may work. The steps in this simulation are as follows:

(a) Produce $N \sim 10^6$ points randomly in a unit cube.
(b) Around a fraction $f = 1 - \exp(-3Q/P)$ of these points produce a randomly oriented neighbour within a distance $xN^{-1/3}$, where x is a fraction less than 1.
(c) Expand the cube and all scales within it homologously in the ratio $\exp(Q/P)$ in all directions.
(d) From the expanded cube retain the central cubical portion of unit size, deleting the rest.

These operations describe the creation process during one QSSC cycle. We repeat this exercise many times to see how the distribution of points evolves. A slice of the cube after five cycles clearly shows that the distribution of points has developed clusters and voids, typically like that in the real universe. A two-point correlation analysis confirms this visual impression quantitatively. The distribution approximates after a few cycles, to a power law with index -1.8. The relative ease with which this type of distribution can be generated is in sharp contrast to the not inconsiderable efforts spent in standard cosmology in arriving at a cluster + void distribution through gravitational clustering.

6. Some decisive tests for the QSSC

We next outline a few tests which hold the potential of either confirming or disproving predictions of the QSSC.

(1) *The discovery of epochs of ultra-high redshifts:* As we have seen, the QSSC model has a maximum redshift in the present cycle. In the typical case described here, $z_{\max}$ was taken as 5. There is sufficient flexibility in the model to make $z_{\max}$ somewhat higher, say upto 10–15. However, any direct evidence that the universe had passed through an epoch of much higher redshifts, say $\geqslant 30$, would bring the credibility of QSSC into question. (Light nuclear abundances or the microwave background as known today *do not* constitute such evidence since these are so interpreted only within the SC framework: they have a different interpretation in the QSSC.)

A large population of such objects are not expected at $z > 30$ in the SC either. However, a small number of such objects could possibly be explained as arising due to very large fluctuations of the Gaussian random field in SC while it is impossible to accommodate them in the QSSC in any manner.

(2) *Finding very old matter:* Just as detection of old matter goes against the SC, so will the nondetection of such matter go against the QSSC. As the QSSC claims the observable universe to contain very old stars, dedicated searches for such objects are important to test the theory. In this connection, it is worth noting that current findings by gravitational microlensing would rule out white dwarfs of 10–12 Gyr age as they would be luminous: however, they are consistent with white dwarfs as old as 40–50 Gyr.

(3) *Evidence for metallic whiskers:* The thermalizers of the relic stellar radiation needed to produce the microwave background, viz, the metallic whiskers in interstellar and intergalactic space, hold the lifeline to the QSSC. Narlikar et al. [28] have discussed how these are produced and distributed in space, pointing out preliminary evidence consistent with their existence. Such evidence needs to be critically examined to see if such dust indeed exists. Finding evidence for such whiskers will definitely enhance the credibility of the QSSC.

In this connection the m–z relation using Type Ia supernovae out to $z > 1$ can play a crucial role. So can high redshift quasars showing substantial luminosity in the millimetre wavelengths. The finding of such quasars either means that they must be abnormally luminous in millimetre wavelengths, or that their redshifts are substantially noncosmological, a possibility that has not been fully ruled out [3,26]. Failing these two alternatives, the QSSC loses one of its main arguments.

(4) *Evidence for explosive events:* The QSSC claims that the pockets of high energy emission in the universe like the active galactic nuclei are explosive events pouring new matter into the universe. It questions the black hole paradigm which invokes infalling matter circulating in an accretion disc. As observational tools improve, the nuclear region can be examined more critically to see which of the two alternatives is correct. Since the SC is not related to the black hole/accretion disc paradigm, finding it (or not finding it) will not affect it seriously. However, the QSSC is more critically linked with the creation paradigm.

(5) If a few light sources like galaxies or clusters are found with modest ($\sim$0.1) *blueshifts*, they can be identified with those from the previous QSSC cycle, lying close to the epoch of the maximum scale factor. In standard cosmology there should be no blueshifts.

(6) If low mass stars, say with half a solar mass, are found in red giant stage, they will have to be very old, say ~40–50 Gyr old, and as such they cannot be accommodated in the standard model, but will naturally belong to the previous cycle of the QSSC.

(7) If the dark matter in the galaxies is proved largely to be baryonic, or if other locations like clusters of galaxies turn out to have large quantities of baryonic matter, then the standard cosmology would be in trouble. For, beyond a limit the standard models do not allow for baryonic matter as it drastically cuts down the predicted primordial deuterium and also spoils the scenario for structure formation.

These observations lie just beyond the present frontiers of astronomical observations. So there is hope that the cosmological debate will spur observers to scale greater heights and push their observing technology past the present frontiers, as happened fifty years ago during the debate between the original steady-state cosmology vs the standard big bang cosmology.

7. For further reading

[38–49].

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