

## The quasi-steady state cosmology

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**ABSTRACT.** This paper begins with a discussion of the shortcomings of standard cosmology, and then outlines an alternative cosmology called the Quasi-Steady State Cosmology (QSSC). The theoretical framework and observational tests of the QSSC are next described. Finally some tests which can distinguish between the standard big bang cosmology and the QSSC are briefly mentioned.

**Key words:** cosmological models, observational tests, alternative cosmologies, creation of matter, microwave background, light nuclear abundances.

**RESUMO. A cosmologia do estado quase-estacionário.** Discutem-se em primeiro lugar as falhas na cosmologia oficial, seguido por uma breve descrição da cosmologia alternativa chamada Cosmologia do Estado Quase Constante. Descrevem-se também o arcabouço teórico e os testes referentes a CEQC. Por último, são mencionados os testes que testemunham a distinção entre a cosmologia oficial do *Big Bang* e a CEQC.

**Palavras-chave:** modelos cosmológicos, testes de observação, cosmologias alternativas, criação de matéria, fundo de microondas, abundâncias nucleares de luz.

Modern 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*. The general belief in a static universe in which the galaxies etc., are at rest was so strong that when in 1922 Aleksandr Friedmann proposed expanding models of the cosmos, they were largely ignored by everybody, including Einstein. However, the first significant observational result in cosmology came in 1929 when Edwin Hubble announced the velocity-distance relation for galaxies, based on the redshifts observed in their spectra and their apparent magnitudes. This led people to a paradigm-shift that the universe is not static but *expanding*. And the Friedmann models, which had also been independently found by Abbe Lemaitre in 1927, 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 primordial "atom". In modern jargon this is identified with the state of "big bang".

For a decade or so after World War II, George Gamow, Ralph Alpher, Robert Herman 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 soon encountered a basic difficulty that made it clear that this programme could not be carried out, because of the absence of stable nuclei at mass numbers 5 and 8. But as Alpher and Herman (1948) pointed out, *if* there had been such an early ultradense stage, the universe might well contain an expanding cloud of primordial radiation that would preserve its blackbody form as it evolved.

In the 1940s, however, another new idea challenging this hot big bang picture appeared on the scene, when three British astrophysicists, Hermann Bondi and Tommy Gold (1948) as well as Fred Hoyle (1948) 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 the universe. Hoyle in fact proposed a slight modification of Einstein's general relativity 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; but taking into consideration the fact that space was expanding, 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 (in violation of the energy conservation law). Instead there was a steady expansion supported by a continuous creation of matter. In 1948, the estimates of the age of the big bang universe showed it to be very small (of the order of  $2 \times 10^9$  years), smaller than the geological age of the Earth ( $\sim 4.6 \times 10^9$  years). 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 5-10. Even today, 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, however, swung the argument in favor 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. However, as we will now discuss, this reasoning may have been too simplistic. We will begin with a discussion of some weaknesses of the standard model.

### 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 favor of the standard model.

**The origin of light nuclei.** In the mid-sixties, Robert Wagoner, William Fowler and Fred Hoyle (1967) 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,  $^3\text{He}$ ,  $^4\text{He}$ , and  $^7\text{Li}$  that were in satisfactory agreement with astrophysical observations if the average cosmological density  $\rho$  (in  $\text{g/cm}^3$ ) of baryonic matter was related to the radiation temperature  $T$  (in Kelvin) by a finely tuned relation:

$$\rho = 10^{-32} T^3. \quad (1)$$

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  $\rho - T$  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,  $T = 2.73 \text{ K}$ , yields about  $2 \times 10^{-31} \text{ g/cm}^3$  for the present-day average density of the cosmos. For a comparison, the standard model predicts the present density of the universe to be close to  $2 \times 10^{-29} \text{ g/cm}^3$ . This density is sometimes referred to as the *closure density*: models denser than this are closed in the topological sense, while those with less density are open. Thus there is a big discrepancy between observation and theoretical prediction.

Although the predicted density 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 favored species has changed its identity over the years from massive neutrinos to esoteric "cold-dark matter" particles or WIMPs, perhaps with some remaining admixture of neutrinos. Evidently, it is not reassuring that this line of reasoning from the 1960s is still the best available in favor of Big Bang cosmology, despite the continuing failure of attempts to identify the required nonbaryonic matter.

**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 (Mather *et al*, 1990). However, the

weakness of the argument lies in its inability to predict the actual temperature of the radiation at the present epoch. Guess estimates have ranged from 5 K to 50 K (*see* Assis and Neves 1995). 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  ${}^4\text{He}$  is synthesized from hydrogen in stars with an energy yield of about  $6 \times 10^{18}$  ergs for each gram of helium, the energy being radiated by the stars to produce a radiation background. If all of the  ${}^4\text{He}$  in the universe has been produced in this way (the observed abundance is about one  ${}^4\text{He}$  for every 12 hydrogen atoms), then the accompanying radiation background should have an energy density of

$$u = 4.37 \times 10^{-13} \text{ erg/cm}^3. \quad (2)$$

That is quite close to the observed energy density of the microwave background, namely  $4.18 \times 10^{-13}$  erg/cm<sup>3</sup>.

Either this agreement is coincidental, or we must conclude that the  ${}^4\text{He}$  was created, not by Big Bang nucleosynthesis, but rather by hydrogen burning inside stars (a process that we know to exist), and that the radiation background from stars has become subsequently thermalized into the far infrared (as discussed in section 5).

**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  $S(t)$ , 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?

In attempts to answer this question, it is accepted that particle energies increase up to values in the TeV range, and then, by speculation, all the way to the Big Bang. 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 initial 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, we are in fact not able to satisfy the "repeated testability" criterion of a physical theory.

Weinberg (1989) 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  $\Lambda$ , arising from the vacuum. If today we wish to claim a relic  $\Lambda$ , then we have to assume that it is an extremely tiny ( $\sim 10^{-108}$ ) fraction of the original value at the time of inflation. Why was the relic value so finely tuned to what is claimed to be its observationally estimated value today?

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

These and some other unsatisfactory features (for a detailed discussion see Arp *et al.* 1990) led Fred Hoyle, Geoffrey Burbidge and Jayant Narlikar (1993) to take a fresh look at cosmology and try a new approach which they named the "Quasi-Steady State Cosmology".

### The quasi steady-state cosmology

This alternative cosmology makes a beginning from an action principle that seeks to explain how matter and radiation appeared in the universe. That is to say, the action principle includes the possibility that a typical world-line of a particle can have a beginning. The details involve a scalar field analogous to that which appears in popular inflationary models which are favored by standard cosmology. As it does in the inflationary models, the scalar field exerts a negative pressure that explains the universal expansion. In this theory, the field also acts negatively in the creation process, balancing the positive energy of matter production. That permits new matter to appear in an already existing universe, instead of requiring the creation of the entire universe *de novo*, in a *Big Bang*.

The creation is being triggered locally in what are called *minicreation events* or *minibangs*, with the negative field component subsequently escaping from the region of creation, which has experienced

an accumulation of positive energy. It is in this way that black holes are formed - not through the infall of matter. The popular black hole paradigm at present assumes that the high energy activity in the nuclei of certain "active" galaxies is triggered by a spinning massive black hole with several billion solar masses. However, this interpretation runs into problems like the following.

Matter moving at velocity  $c$  transverse to the radius vector from the center of a spherical black hole of mass  $M = 10^{10}$  solar masses ( $M_{\odot}$ ), at the critical distance  $2GM/c^2$ , has angular momentum of order  $10^{26}$  cm<sup>2</sup>/s per gram. But matter rotating about a galactic center typically has ten thousand times more angular momentum than that. Therefore it is difficult for us to see how a large quantity of matter in a galaxy could come to be packed into the small scale of a black hole, even when the black hole has a mass as large as  $10^{10}$  solar masses.

The conventional interpretation has as yet found no satisfactory way around this difficulty. But if, at the centers of galaxies, there are black holes that act as minicreation events, the escape of the negative energy field generated in the creation process provides a ready explanation for the accumulation of the positive material component, leading to an easily understood development of the central black hole.

While there are several interesting applications of this idea to high energy astrophysics, the present discussion will be confined to cosmology. Consider first how the combined effect of such minicreation events drives the dynamics of the universe. It turns out that while the long-term result of this interaction is the steady state model, there are significant short term effects which make the universe oscillate around the steady state solution. Which is why the cosmology is called the "*quasi-steady state*" cosmology.

### Cosmological solutions

The spacetime geometry of the quasi-steady state cosmology (QSSC in brief) is described, just as in standard cosmology, by the Robertson-Walkar line element, with the expansion of the universe determined by the scale factor  $S(t)$ . The difference in this theory from the standard cosmology is that the equation for the square of the time derivative of  $S$  now carries a negative term that decreases like  $S^{-4}$ . Thus, in a time-reversed picture, in which the scale factor  $S$  grows smaller, a stage will eventually be reached beyond which this new term will dominate over the *positive* term, due to the material content of the universe, that goes like  $S^{-3}$ .

The effect, as one goes backward in time, is to produce an *oscillation* of the scale factor:

$$S(t) = \exp(t/P) \cdot [1 + \eta \cos 2\pi\tau(t)/Q]. \quad (3)$$

The function  $\tau(t)$  is very nearly  $\sim t$ , except near the minima and maxima of the scale factor. The universe oscillates between finite bounds, as the parameter  $\eta$  is nonzero and has magnitude less than unity. The parameter  $Q$  is the temporal period of the periodic part of the scale factor, which turns out to be 5-10 times longer than the "age of the universe" arrived at in the Big Bang scenario. The other characteristic-time parameter,  $P \gg Q$ , describes an exponential growth that is very slow on the time scale of the periodic function.  $P$  is determined by the rate of matter creation averaged over a large number of minicreation events.

The quasi steady-state model also has two other dimensionless parameters: the ratio  $S_{\max}/S_{\min}$  between the amplitudes of  $S(t)$  at its maxima and minima, and the ratio  $S(t_0)/S_{\min}$  of the present scale factor to its periodic minimum.

Typical values of these four parameters that give a good fit to the observational data are

$$Q = 4.4 \times 10^{10} \text{ years}, P = 20Q,$$

$$S_{\max}/S_{\min} = 9 \text{ and } S(t_0)/S_{\min} = 6.$$

The cycles may be looked upon as having the same physical conditions, with star formation, galaxy formation etc. going on in successive cycles in exactly similar fashion. Stars with mass  $\sim M_{\odot}$  will complete their evolutionary lifetime well within one cycle and would be seen as very faint white dwarfs in the next. Structure on the scale of galaxies may take longer to establish, although each cycle will have fully formed galaxies, clusters, superclusters, etc. We will return to these issues shortly.

Among the broad observational data that these parameters must reproduce are (1) the relationship between the redshifts of galaxies and their visual magnitudes, (2) the angular sizes of quasars at different redshifts, (3) the population counts of galaxies and radio sources, (4) the largest observed redshifts, (5) the microwave background and (6) the cosmic abundances of the lightest nuclear isotopes. We begin with the discussion of the microwave background first, as it represents the *tour de force* for the standard model.

### The microwave background

As seen in the cosmological model described above, the stars shining in the previous cycles would

leave a relic radiation background. This can be estimated with the help of starlight distribution in the present cycle, since all cycles are ideally identical. It turns out that the total energy density of this relic starlight at *the present epoch* is adequate to give a radiation background of  $\sim 2.7$  K, in good agreement with the observations. The question is, would this relic radiation be thermalized to a near-perfect blackbody spectrum and distributed with a remarkable degree of homogeneity?

The answer to the first question is “yes”. The thermalizers are metallic whiskers which work most efficiently for this process, much more than the typical spherical grains. These are formed when supernovae make and eject metals in vapor form.

Experimental work on the cooling of carbon and metallic vapors has shown that there is a strong tendency for condensates to appear as long thread-like particles, often called whiskers. Carbon and metal whiskers are particularly effective at converting optical radiation into the far infrared. Calculations show that a present-day intergalactic density of  $10^{-35}$  g/cm<sup>3</sup> for such whiskers would suffice to thermalize the accumulated starlight at an oscillatory minimum. Such a whisker density could readily be accounted for by the ejecta of supernovae, which can easily leave the confines of their parent galaxies. For details of this process see Narlikar *et al.* (1997).

However, close to an oscillatory maximum, the universe is sufficiently diffuse that such intergalactic particles have a negligible effect on starlight. Light propagation is then essentially free and, because of the long time scale of the maximum phase of each cycle, there is a general mixing of starlight from widely separated galaxies. Because of this mixing and the large-scale cosmic homogeneity and isotropy, the energy density of the radiation also acquires a high degree of homogeneity. That homogeneity persists, because the absorption and reemission of the starlight at the next minimum does not change the energy density. Thus we have an explanation of the remarkable uniformity of the cosmic microwave background.

Small deviations from this uniformity, to the order of a part in  $10^5$ , are expected for regions near rich clusters of distant galaxies. This implies that the microwave background should exhibit temperature fluctuations on the sky of a few tens of microkelvin on an angular scale determined by the clustering of distant galaxies. For a distant cluster of diameter 10 megaparsecs observed at a redshift  $z \equiv \Delta \lambda / \lambda$  of 5 (about the highest redshift that's been seen), that angular scale is about  $0.7^\circ$ , in good agreement with

the largest observed fluctuations in the microwave background.

The ease with which the complexities of the microwave background can be understood in the quasi steady-state cosmology is a strong indication that the theory is on the right track. Rather than being put in by parametric choices, the observed fluctuations of the microwave background arise naturally from the clustering of galaxies.

### Origin of the light nuclei

There are more than 320 known isotopes of the elements. In their pioneering work, Margaret and Geoffrey Burbidge, Willy Fowler and Fred Hoyle (1957; these authors are collectively referred to as B<sup>2</sup>FH) showed that, with the possible exceptions of deuterium, <sup>3</sup>He, <sup>4</sup>He, <sup>6</sup>Li, <sup>7</sup>Li, <sup>9</sup>Be and <sup>10</sup>B, and <sup>11</sup>B, all the isotopes were synthesized by nuclear processes in stellar interiors. In 1957, these eight nuclei seemed hard to produce in stellar conditions. Some recent developments regarding these light nuclei are worth reviewing in this context. For details see Burbidge and Hoyle (1998).

The list of eight problematic cases was soon reduced to five, as <sup>6</sup>Li, <sup>10</sup>B, and <sup>11</sup>B were found to be produced in the spallation reactions of cosmic rays. More recently, it has been found that the depletion of Fe in old stars correlates closely with the abundance of <sup>9</sup>Be, strongly suggesting that <sup>9</sup>Be was produced in association with the iron in supernovae. Thus Burbidge and Hoyle (1998) have argued that the original list of eight light nuclear species that at one time were candidates for association with a hot Big Bang cosmology gets reduced to four. Of these, lithium can possibly be made under stellar circumstances, in view of the finding of lithium rich supergiant stars.

Restressing the striking fact that the energy density of the microwave background is very close to what we calculate for the production of the observed <sup>4</sup>He abundance solely by hydrogen burning in stars, one is left with essentially only two of the eight special cases, namely deuterium and <sup>3</sup>He.

What is the likelihood, we now ask, that even these last two will turn out to have purely astrophysical origins? <sup>3</sup>He is accumulated in large quantities in dwarf stars whose masses are too small for the isotope to be destroyed by the radiation <sup>3</sup>He + <sup>3</sup>He → <sup>4</sup>He + 2p. There is also a class of earlier-type, more massive stars (including 3 Cen A), in which *most* of the helium is <sup>3</sup>He. On the  $Q \approx 10^{11}$  year time scale of the quasi steady-state cosmology, it seems likely that the cosmic abundance of <sup>3</sup>He

(Big Bang nucleosynthesis predicts about one for every ten thousand  $^4\text{He}$  nuclei) is to be explained by an escape from stars of these types in stellar winds.

Deuterium, the last survivor from the original list of problematic light nuclei, is a particularly difficult case. It is both produced and destroyed by astrophysical processes. Deuterons are made in high-energy processes such as solar flares that generate free neutrons, and destroyed by burning in stellar interiors. Arguments over whether astrophysical production suffices, with no need to invoke cosmological deuteron production, therefore turn on measurements of the cosmic D/H abundance ratio, which are difficult to accomplish with precision. In these circumstances, the deuterium case can reasonably be regarded as uncertain. With all other nuclides (except, of course,  $^1\text{H}$ ) produced in adequate abundance by astrophysical means, it would seem best to extend this generalization to the deuteron and presume that any nucleus heavier than the proton has been synthesized by processes associated with stars. In short, Burbidge and Hoyle argue that a supposedly strong evidence for a hot dense phase in the universe becomes considerably weaker by the viability of an alternative stellar scenario for nucleosynthesis of light isotopes.

### Observations of discrete sources

One of the most interesting developments in recent times in extragalactic astronomy is the use of Type IA supernovae to determine distances of galaxies and using the results to test the redshift-distance relations predicted by different cosmological models. Standard cosmology, after years of discounting the cosmological constant introduced by Einstein (1917) in his static model as unnecessary, suddenly found it a very attractive parameter! As mentioned earlier, there are two reasons for the same: (i) that the age of the universe comes out too low for comfort when compared to the estimated ages of stars and galaxies and (ii) the extension of Hubble's law to distant galaxies does not fit the standard models. By introducing the cosmological constant these difficulties can be overcome. However, we have already referred to the fine-tuning needed to get the required value of the cosmological constant at the present epoch in the standard model.

On the other hand, Banerjee, *et al.* (2000) have shown that there is excellent agreement between the Hubble relation based on the measured distances of galaxies, using Type IA supernovae and the predictions of the QSSC. This happens precisely

because of the absorption caused by intergalactic dust postulated by the QSSC to thermalize the microwave background. So far as stellar and galactic ages are concerned, the long time scales of the QSSC model ensure that there are no such problems.

There are also excellent agreements on two other cosmological tests. In one we look at the angular sizes of the tiny cores of distant radio sources whose redshifts are known. The angular size redshift relation predicted by the QSSC provides a very good fit to the data (for details see Banerjee and Narlikar, 1999). The other test counts radio sources up to varying levels of flux density. This number-flux density relation can also be closely simulated by the QSSC (Hoyle *et al.* 1994, 1995).

### The minicreation events, dark matter and active nuclei

During the period 1958-64, 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 protogalaxies 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 way out nowadays is to assume that such groupings are indeed gravitationally bound – by large quantities of unseen “dark matter”. This conjecture was already put forward by Fritz Zwicky in the 1930s for some of the great clusters of galaxies. In the 1970s, the view that the masses of systems of galaxies on all scales are proportional to their sizes became widely believed. However, 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 mini-creation events and that their excess kinetic energy is the result of their explosive origin. As we shall see later in this article, 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 life-span 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 galactic nuclei asserts that, in all such situations, there is a massive black hole at the center 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 centers 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.

### Large scale structure

The minicreation centers act as nuclei for large scale structure. Ali Nayeri, Sunu Engineer, Fred Hoyle and this author (1999) 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 neighbor within a distance  $\propto N^{-1/3}$ , where  $\propto$  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 5 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. After a few cycles the distribution approximates 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.

### Concluding remarks

What are the specific tests that may distinguish the QSSC from standard cosmology? A few are as follows:

1. 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 cycle, lying close to the epoch of the maximum scale factor. In standard cosmology there should be no blueshifts.
2. If low mass stars, say with half a solar mass, are found in red giant stage, they will have to be very old, say  $\sim 40 - 50$  Gyr old, and as such they cannot be accommodated in the standard model, but will naturally belong to the previous cycle of the QSSC.

3. 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 and the standard big bang cosmology.

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