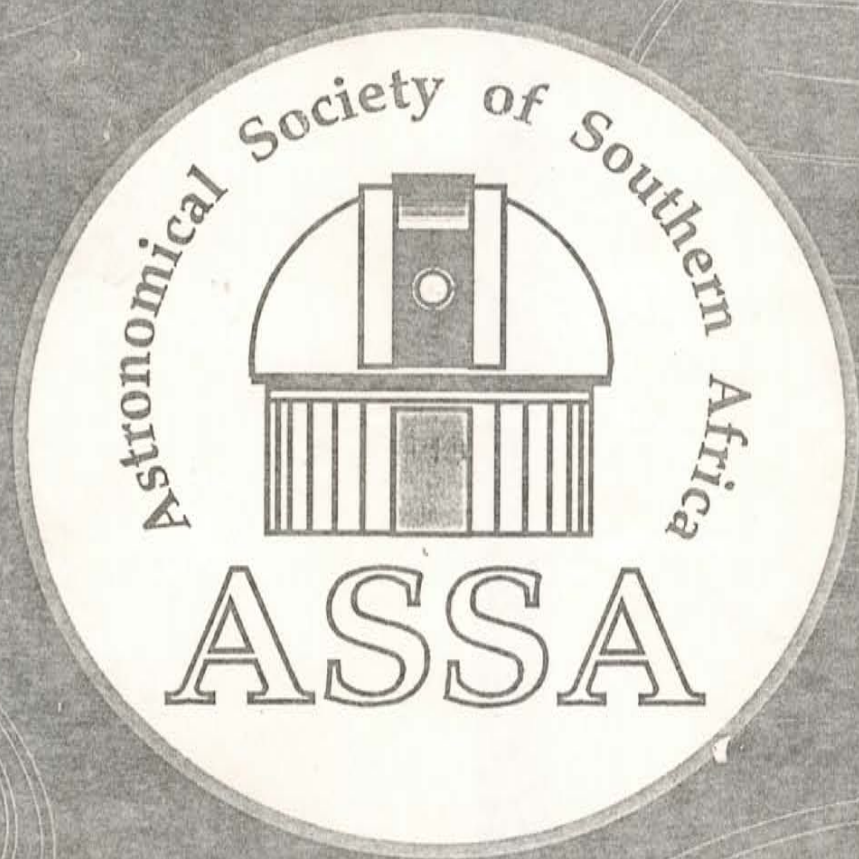


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Quasi Steady State Cosmology

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Abstract

Because of a number of unsatisfactory features of the standard hot big bang cosmology, it is argued that there is a case for exploring alternative approaches to cosmology. The approach described here attempts to relate the large scale features of the universe to the basic phenomenon of creation of matter.

This theory, called the quasi steady state cosmology (QSSC), begins with a field theoretic description of matter creation within the framework of general relativity. A scalar field C of zero restmass but negative energy and stresses interacts with matter at the instants of creation thereby preserving the law of conservation of the universe expanding at an overall exponential rate along with cycles of expansion and contraction with shorter time scales.

It is argued that such a solution arises from mini-creation events taking place near the event horizons of highly collapsed massive objects. The now familiar phenomena like QSOs, AGN, radio sources, etc. are the manifestations of matter creation in such events. These events are cophased and the oscillations occur because of feedback between the creation process and the expansion of space. In this way the cosmology is seen to be related to high energy astrophysics in a very direct way.

The QSSC can explain the abundances of light nuclei and the microwave background, the observed large scale features of the universe like the $m - z$ relation, the source count, the angular size-redshift relation, as well as the observed distribution of the ages of galaxies. This work gives a brief review of these properties of the quasi steady state cosmology.

1 Introduction

The standard big bang cosmology has the universe created out of a primeval explosion that not only created matter and radiation but also spacetime itself. The big bang event itself cannot be discussed within the framework of a physical theory but the events following it are in principle considered within the scope of science. The recent developments on the frontier between particle physics and cosmology highlight the attempts to chart the history of the very early universe.

Exciting though these studies are, they have failed to resolve some of the basic issues of cosmology. These issues can be stated briefly as follows:

1. The microwave background radiation (MBR) is considered a fundamental proof of the big bang cosmology. Yet, cosmological considerations so far have failed to deduce its present temperature of $2,73K$.
2. While the Planckian spectrum of the MBR is deduced from its relic interpretation, its small scale anisotropy has not been successfully related to the observed large scale inhomogeneity of matter distribution in the universe, the recent findings of the satellite COBE notwithstanding.
3. There is no consistent theory of structure formation that takes in a reasonable hypothesis of dark matter and can reproduce the observed large scale structure and motions from primordial seed fluctuations.
4. The claims of explaining the large scale features of the universe in terms of discrete source populations inevitably require epicyclic hypotheses of evolution of physical properties of these sources that are post-facto rather than having any predictive power.
5. The age distribution of galaxies poses many problems for the canonical big bang model. How to accommodate globular clusters of ages $15-18 Gyrs$ in a big bang universe with $k = 0$, that is required by inflations in the very early phase? Equally difficult it is to understand the existence of very young galaxies at the present epoch, for, galaxy formation is supposed to have taken place in the early universe.
6. The phenomena in high energy astrophysics like the QSOs, AGN, radio sources, etc. show big outpourings of matter and energy from compact regions. However these events have no relation to the primordial big bang which is totally isolated from this relatively recent activity.
7. Finally, on a theoretical issue the big bang itself is an inconsistency. Its existence is deduced from the equations of general relativity which are derived from an action principle. Yet, the big bang itself is seen as a spacetime singularity arising from these very equations and at the singularity the action principle breaks down. Thus the cycle of reasoning is self-contradictory and the question of the origin of matter remains not only unsolved but is declared unsolvable.

For details of these points see earlier work of Arp et al (1990) and Hoyle et al (1993). At a nontechnical level I have discussed these ideas in the New Scientist (Narlikar 1991, 1993). My main purpose here is to argue that despite the popularity enjoyed by the big bang cosmology today, the above list is sufficient to motivate an alternative approach to cosmology.

Any alternative to big bang cosmology should fulfill a few minimum conditions. First it must do at least as well as the big bang cosmology in explaining the MBR and light nuclear abundances and in describing the observed features of discrete source surveys. Next it must try to do better than the big bang model on some of the abovementioned fronts. Finally, as a scientific theory it must make a few disprovable predictions that distinguish it from the standard model.

In the remaining part of this work I will describe a model that claims to do just that. This is the quasi steady state cosmology (QSSC) proposed by Fred Hoyle, Geoffrey Burbidge and myself. The first paper in the series on this topic is referred to above (viz. Hoyle et al 1993) while others are in various stages towards publication. Further details of the present concise account may be found there.

2 Creation of matter

In 1948 Bondi and Gold (1948) and Hoyle (1948) had independently proposed the steady state theory as an alternative to the big bang cosmology. Bondi and Gold had adopted the Perfect Cosmological Principle as the starting point of their approach while Hoyle had taken the phenomenon of matter creation as the main motivation. Here we will follow the second approach but with some significant modification.

As mentioned in Point 7 against the big bang, a scientific theory of cosmology should provide a consistent description of matter creation; eg., a theory in which the phenomenon is described within the action principle formulation which has proved so universally useful in theoretical physics. Point 6 further provides a clue that the creation should occur in small bursts rather than in one big bang. The steady state theory on the other hand met these objections only half way. While it did provide a field theory for matter creation, it assumed that creation takes place in a homogeneous and isotropic way. The resulting steady state model was too simple and constrained to explain the variety of cosmological observations and was thus disproved.

The QSSC, however, introduces an important modification of the above simple steady state concept by arguing that creation takes place only in the vicinity of collapsed massive objects. The feedback of creation on the geometry of spacetime then determines the expansion of the universe which is no longer the de Sitter expansion of the old steady state model. To see this we look at the field equations that govern the large scale structure of the universe.

The field equations are derived from an action principle. Although Hoyle et al (op. cit.) considered a direct particle interaction approach motivated by Mach's Principle, the following simplified derivation essentially reproduces their equations in the more familiar field theory format. Thus the classical Hilbert action leading to the Einstein equations is modified by the inclusion of a scalar field C whose derivatives with respect to the spacetime coordinates x^i are denoted by C_i . The notation followed here is that of my textbook on cosmology (Narlikar 1993) where further details may be found. The action is given by

$$A = \sum_a \int_{\Gamma_a} m_a c ds_a + \int_v \frac{c^3}{16\pi G} R \sqrt{-g} d^4x - \frac{1}{2c} f \int_v C_i C^i \sqrt{-g} d^4x + \sum_a \int_{\Gamma_a} C_i da^i \quad (1)$$

where C is a scalar field and $C_i = \partial C / \partial x^i$. f is a coupling constant. The last term of (1) is manifestly path-independent and so, at first sight it appears to contribute no new physics. The first impression, however, turns out to be false if we admit the existence of broken worldlines.

Thus, if the worldline of particle a begins at point A , then the variation of A with respect to that worldline gives

$$m_a \frac{da^i}{ds_a} = g^{ik} C_k \quad (2)$$

at A . In other words, the C -field balances the energy-momentum of the created particle. The field equations likewise get modified to

$$R_{ik} - \frac{1}{2} g_{ik} R = -\frac{8\pi G}{c^4} \left[\frac{T_{ik}}{m} + \frac{T_{ik}}{c} \right] \quad (3)$$

where

$$\frac{T_{ik}}{c} = -f \left\{ C_i C_k - \frac{1}{2} g_{ik} C^l C_l \right\}. \quad (4)$$

Thus the energy conservation law is

$$\frac{T_{ik}}{m}{}_{;k} = -\frac{T_{ik}}{c}{}_{;k} = f C^i C_{i;k}. \quad (5)$$

That is, matter creation via a nonzero left hand side of (5) is possible while conserving the overall energy and momentum.

The C -field tensor has negative stresses which lead to the expansion of spacetime, as in the case of inflation. The formalism described here is essentially that used by Hoyle and Narlikar (1962, 1966 a,b) in the 1960s to produce inflation type solution (which, of course predated Guth's inflationary cosmology by 15 years!).

From (2) we therefore get a necessary condition for creation as

$$C_i C^i = m_a^2 c^4; \quad (6)$$

This is the "creation threshold" which must be crossed for particle creation. How this can happen near a massive object, can be seen from the following simple example.

The Schwarzschild solution for a massive object M of radius $R > 2GM/c^2$ is

$$ds^2 = c^2 dt^2 \left(1 - \frac{2GM}{c^2 r} \right) - \frac{dr^2}{1 - \frac{2GM}{c^2 r}} - r^2 (d\theta^2 + \sin^2 \theta d\phi^2), \quad (7)$$

for $r \geq R$. Now if the C -field does not seriously change the geometry, we would have at $r \gg R$,

$$\dot{C} \approx \alpha, C' \equiv \frac{\partial C}{\partial r} \cong 0. \quad (8)$$

If we continue this solution closer to $r \approx R$, we find that

$$C^i C_i \equiv \left(1 - \frac{2GM}{c^2 r} \right)^{-1} \frac{\alpha^2}{c^2}. \quad (9)$$

In other words $C_i C^i$ increases towards the object and can become arbitrarily large if $r \approx 2GM/c^2$. So it is possible for the creation threshold to be reached *near* a massive

collapsed object even if it $C_i C^i$ is below the threshold far away from the object. In this way massive collapsed objects can provide new sites for matter creation. Thus, instead of a single big bang event of creation, we have mini-creation events (MCEs) near collapsed massive objects.

3 A Cosmological Solution

Since the C -field is a global cosmological field, we expect the creation phenomenon to be globally cophased. Thus, there will be phases when the creation activity is large, leading to the generation of the C -field strength in large quantities. However, the C -field growth because of its large negative stresses leads to a rapid expansion of the universe and a consequent drop in its background strength. When that happens creation is reduced and takes place only near the most collapsed massive objects thus leading to a drop in the intensity of the C -field. The reduction in C -field slows down the expansion, even leading to local contraction and so to a build-up of the C -field strength. And so on!

We can describe this up and down type of activity as an oscillatory solution superposed on a steadily expanding de Sitter type solution of the field equations as follows. For the Robertson-Walker line element the equations (3)-(5) give

$$3 \frac{S^2 + kc^2}{S^2} = 8\pi G \left(\rho - \frac{1}{2} f \dot{C}^2 \right), \quad (10)$$

$$2 \frac{\ddot{S}^2}{S} + \frac{\dot{S}^2 kc^2}{S^2} = 4\pi G f \dot{C}^2, \quad (11)$$

where $S(t)$ is the scale factor and k the curvature parameter ($=0, \pm 1$). The cosmic time is given by t . These equations have a de Sitter type solution given by

$$S \propto \exp(t/P), k = 0, \dot{C} = \text{constant}, \rho = \text{constant}$$

The oscillatory solution is given by

$$k = +1, \dot{C} \propto 1/S^3, \rho \propto 1/S^3. \quad (12)$$

Thus (10) becomes, in the latter case

$$\dot{S}^2 = -c^2 + \frac{A}{S} - \frac{B}{S^4}, A, B = \text{constant}. \quad (13)$$

Here the oscillatory cycle will typically have a period $Q \ll P$.

Although the exact solution of (14) will be difficult to obtain, we can use the following approximate solution of (13) and (14) to describe the short-term and long-term cosmological behaviour:

$$S(t) = \exp\left(\frac{t}{P}\right) \left\{ 1 + \alpha \cos \frac{2\pi t}{Q} \right\}. \quad (14)$$

Note that the universe has a long term secular expanding trend, but because $|\alpha| < 1$, it also executes non-singular oscillations around it. We can determine α and our present

epoch $t = t_0$ by the observations of the present state of the universe. Thus an acceptable set of parameters is

$$\alpha = 0.75, t = 0.85Q, Q = 4 \times 10^{10} \text{ yr.}, P = 20Q. \quad (15)$$

Although the set is not unique and there will be a *range* of acceptable values, we will work with this set to illustrate the performance of the model.

4 The Origin of Nuclei and the Microwave Background

We have as yet not said what particle is being created by the C -field. The answer is, the Planck particle whose mass is

$$m_P = \sqrt{\frac{3h}{4\pi G}} \sim 10^{-5} g \quad (16)$$

This particle, however, has a very short lifetime

$$\tau_P \sim \sqrt{\frac{Gh}{c^5}} \sim 5 \times 10^{-44} s. \quad (17)$$

It decays ultimately into the baryon octet and radiation. Most members of the octet except n and p are also short-lived and decay into protons. Only the neutron and the proton live long enough to combine into helium nuclei. Thus approximately 25% by mass (2 out of 8 baryons) combine to form helium.

A more careful calculation gives the helium mass fraction to be around 23%, with a tiny fraction of 1-2% in the form of metals. This type of nucleosynthesis also generates ^2H , ^3H , ^3He , ^6Li , ^7Li , ^9Be , ^{10}B etc. in small amounts that are in agreement with the observations. In fact, the light nuclear abundances in this cosmology lead to a better agreement with observations than in the big bang model.

There is one further important consequence. In the big bang model the required production of deuterium imposes a stringent upper limit on the present day baryon density. This limit forces us to assume that the dark matter component of the universe must be largely nonbaryonic. In the QSSC, there is no such density limit from deuterium abundance and thus the dark matter component *can be baryonic*. We will discuss this point further in the following section.

What about the microwave background? The QSSC obtains it in the following way. First, each Planck particle decay is like a fireball: it produces a lot of energy, including baryons ($\sim 10^{19}$ per Planck particle) and radiation. More than the hot big bang, the Planck fireball can provide several interesting and realistic studies in astroparticle physics. Further, since the Planck fireballs are repeated phenomena, rather than the "once only" type situation of the hot big bang cosmology, they are amenable to a more exhaustive scientific study.

Bulk of the fireball energy goes into expansion. However, some radiation remains as relic of the fireball. Together with the starlight generated in the preceding oscillatory

cycles this energy is to be thermalized to provide the microwave background. Does it provide enough radiant energy to give a 2.7 K background? Is the background thoroughly thermalized to produce a black body spectrum? Also, is it homogeneous to the extent given by COBE (Smoot, et al 1992) and other measurements?

The answer to all these questions is in the affirmative as we shall now demonstrate.

Let us consider the present day energy density of intergalactic starlight which comes largely from old star populations. Taking into consideration the usual estimates of 10^{-14} erg cm^{-3} for starlight in the visible spectral region, we get the total (in all wavelengths) starlight energy density as $\sim 2 \times 10^{14}$ erg cm^{-3} . Using (16) we estimate the average starlight production rate per unit volume per unit time as

$$\epsilon = 1.14 \times 10^{-13} \text{ erg cm}^{-3} Q^{-1}. \quad (18)$$

Thus the total amount of starlight produces from the previous oscillatory minimum at $t = -0.5Q$ to $t = 0.5Q$ (the last minimum) is

$$\epsilon \int_{-0.5Q}^{0.5Q} \frac{dt}{1+z} \approx 4.56 \times 10^{-13} \text{ erg cm}^{-3}. \quad (19)$$

Now the weakening [due to the expansion factor ($\exp t/P$) in each cycle] of energy density W_{\min} at the oscillatory minimum is $4Q/P \times W_{\min}$. This must be replenished by fresh thermalization of starlight produced. Thus in the steady state we get for $P = 20Q$,

$$W_{\min} = 1.14 \times 10^{-13} \times \frac{P}{Q} = 2.28 \times 10^{-12} \text{ erg cm}^{-3}. \quad (20)$$

This is with respect to coordinate volume. To convert it to proper volume we need to introduce the redshift effect from $t = 0.5Q$ to $t = t_0$, which is a factor 0.1734. Thus the present energy density is

$$W_{\text{present}} = W_{\min} \times 0.1734 \approx 3.96 \times 10^{-13} \text{ erg cm}^{-3} \quad (21)$$

which corresponds to a black body temperature of 2.68 K - very close to that observed!

Thus quantity-wise the starlight from several past generations of stars is sufficient to maintain a steady background of radiation, provided, some agency is available to thermalize it. The agency proposed is dust in the form of metallic needles, mostly of iron which absorb the ambient radiation and reradiate it in the microwaves. Provided this has gone on long enough, the radiation spectrum will approach the black body form. Calculation shows that indeed the thermalization has occurred through as many as 10^3 absorptions and remissions by iron whiskers - sufficient to ensure an extremely close approximation to the black body curve. The iron whiskers are typically ~ 1 mm in length and 10^{-6} cm in radius of cross section. The iron itself is produced partly from stellar nucleosynthesis in supernovae. The required density in the form of such whiskers is only $\sim 10^{-35}$ g cm^{-3} : well within the observed cosmic abundances of iron.

The background produced will be very smooth with a patchiness of density of the order of 10^{-5} . Fluctuations of density and temperature of this or larger order get smoothed out by redistribution of iron grains by the radiation pressure. On smaller scales the dynamical

smoothness-restoring forces are too small to make the radiation smooth. Thus the COBE finding of $\Delta T/T \sim 10^{-5}$ is consistent with the above picture. Moreover, the characteristic scale of 10^{26} cm at the oscillatory minimum will expand to $\sim 5 \times 10^{26}$ cm at present, giving a characteristic angular scale for the above patchiness to be $\sim 10^\circ$, in conformity with the COBE scale of angular inhomogeneity.

5 Cosmological Surveys

The 1950s and 1960s saw many heated debates on cosmological models in which observational tests of the large scale structure of the universe were used to decide which cosmological models are viable. Thanks to the advances of observational techniques and the growing inputs from physics those attempts now look oversimplified. Nevertheless, observations of the redshift magnitude relation, the counts of radio sources and galaxies, the studies of how angular sizes of radio sources vary with redshifts still serve a useful purpose by putting constraints on the conjectures about the state of the universe in the remote past. I will therefore spend some time on how these observations are expected to turn out in the QSSC.

(i) *The redshift-magnitude relation:* For the oscillatory steady state model the apparent magnitude is not a monotonic function of distance; nor so is the redshift. Thus we get a somewhat unexpected behaviour of z with m with both m and z decreasing as we go past the last oscillatory minimum. The figure could of course be continued to more than one cycle in the past; but the growing faintness of galaxies makes it only an academic exercise.

An important prediction does emerge from the present theory. At magnitudes fainter than, say 24, we may see moderately blueshifted sources from the previous cycle. In this respect we have here a clear distinction from the predictions of the standard models. There may, however, be practical difficulties in detecting blueshifted lines.

(ii) *The counting of radio sources:* Unlike the optical case, the radio sources present a view of the universe extending back to several cycles in the past. In the source count curve calculated for a typical low frequency survey there is a super-Euclidean slope at high flux levels. This arises from contributions of sources from previous cycle in addition to those from the present cycle. We were pleasantly surprised that this and other features of the source count curve observed over a wide range of flux densities from $\sim 10 mJy$ to $\sim 100 Jy$ (see for example Kellermann and Wall 1986) can be matched by our theoretical curve without recourse to any evolutionary parameters.

It is worth pointing out that in this cosmology the redshift of a source cannot tell us how far it is from us. For, a source may be located several cycles back and yet have a modest redshift. Optically such a source may be unobservable, but in the radio it would still have a detectable flux density. Such a source may be classified as an empty field.

(iii) *The angular size-redshift relation:* It was shown by Hoyle (1959) that the angular size of an object does not monotonically decrease with its distance from us in all cosmologies. In a typical Friedmann model the angular size has a minimum at a critical redshift which is model dependent. For example, in the $k = 0$ model the minimum occurs at $z = 1.25$.

This test has not, however, yielded any clearcut answer. There are several observational uncertainties. For example, there is no standard class of sources with a fixed yardstick for linear size. Recent work by Kapahi (1987) suggests that the median angular size falls off as $1/z$ rather than as required by the Friedmann cosmologies. Kellermann (1993) has applied this test to extremely compact radio sources and he reports an upturn in the angular size beyond $z > 1$ or so which he interpretes as being compatible with the standard cosmology with $k = 0$.

A detailed working out of Hoyle's formula for the QSSC shows it also to be compatible with Kellermann's findings. For the larger sources considered by Kapahi and others the linear size would be expected to be more and more compressed as we go more and more towards the oscillatory minimum. Calculations by Hoyle et al (1993: preprint) show that this leads to a fall off not very different from the $1/z$ law found by Kapahi.

6 The MCEs and Astrophysics

The minicreation events (MCEs) have several points of contact with astrophysics. I will briefly enumerate a few:

(i) *Gravity wave sources:* The explosive creation near compact massive objects makes them potential sources of gravity waves, provided the events are sufficiently anisotropic. Narlikar and Das Gupta (1993) have shown that such events in the mass range of 100-1000 M_{\odot} can be detected by the laser interferometric detectors being planned worldwide. Further, the gravity wave background created by such MCEs can also significantly affect the timing mechanism of millisecond pulsars.

(ii) *High energy sources:* The explosive nature of energy generation in QSOs and AGN as well as in the gamma ray burst sources makes the MCSs ideal candidates for these energy sources. This is in keeping with Ambartsumian's conjecture (1988, 1965) that the AGN are likely sites for matter creation in explosive form.

(iii) *The age of the universe:* According to QSSC the universe is infinitely old but the average age of astronomical objects is $1/3P \sim 3 \times 10^{11}$ yrs. This makes many clusters much older than hitherto assumed. Even our Galaxy might have an age of this order with several generations of stars formed, evolved and burnt out. Thus the dark matter component in the Galaxy may be largely made of burnt out stars.

(iv) *Hierarchy of structures:* The largest structure to form in the MCEs is the so called supercluster of mass $\sim 10^{15} - 10^{16} M_{\odot}$. There are, however, MCEs on smaller scales going right down to galactic nuclei with masses $\sim 10^6 - 10^7 M_{\odot}$. It is, however, the former that keep the universe going steady state at all times. Further work is needed, however, in the actual mechanism of galaxy formation from explosively created matter.

7 Concluding Remarks

This approach is intended more in the spirit of opening up the field of cosmology to other ideas than those provided by the standard big bang cosmology. Thus the QSSC, like any scientific theory is to be judged vis-a-vis the big bang cosmology by how it performs

in explaining the observed large scale features of the universe and what testable future predictions it can make.

Even in this alternative cosmology there is considerable scope for inputs from high energy particle physics, in particular (i) in giving more fundamental description to the C -field formalism (which is described here only classically) and (ii) in working out the details of how the created Planck particle decays to baryons.

Some of the main predictions that distinguish the QSSC from big bang cosmology are (i) the existence of faint blue shifted galaxies, (ii) the dark matter turning out to be baryonic, (iii) the existence of very old and very young galaxies, (iv) the detection of gravity waves from the MCEs, and (v) the evidence for matter creation in sources of high energy astrophysics.

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