

CREATION OF MATTER AND ANOMALOUS REDSHIFTS

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Abstract.

This presentation discusses the role of creation of matter in cosmology. While the phenomenon is considered a singular event in the big bang model, a more physical description is given in the quasi-steady state cosmology. Some highlights of this model are presented. Finally, the observations of anomalous redshifts are briefly described and viewed as a consequence of newly created matter ejected from older matter.

1. Introduction

Modern cosmology began in 1917, with Einstein's model of the universe, in which the universe was homogeneous and isotropic and *also static* (Einstein 1917). The general belief in a static universe in which the galaxies etc., are at rest was so strong that when in 1922 Aleksandr Friedmann (1922, 1924) 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 (Hubble 1929). This led people to the interpretation that the universe is not static but *expanding*. And the Friedmann models, which had also been independently found by Abbe Lemaitre (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 primeval 'atom'. In modern jargon this is called 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 concluded that it was dominated by high temperature radiation and other subatomic particles moving at near-light speeds (Alpher, et al 1948). They felt that this was ideally suited for nuclear fusion making all the chemical elements from protons and neutrons. However, they soon learned that this could not be done, because of the absence of stable nuclei at mass numbers 5 and 8. But they also realized that, *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 the universe evolved (Alpher and Herman 1948).

In the 1940s, however, another new idea challenging the hot big bang evolved, and in 1948 three British astrophysicists, Hermann Bondi, Tommy Gold and Fred Hoyle, proposed the *steady state model* (Bondi and Gold 1948, Hoyle 1948). It not only assumed the universe to be homogeneous and isotropic in space, but also unchanging in time. Thus there was no big bang, no hot phase; in fact the universe was essentially without a beginning and would be without an end. *It, however, steadily expanded*, thus creating new volumes of space which got filled up with new matter that was continually created. 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 2×10^9 years), smaller than the geological age of the Earth ($\sim 4.6 \times 10^9$ years).

In the 1950s and the 1960s the debate between the big bang and steady state theories continued unabated. However, two events in the mid-1960s 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 (Hoyle and Tayler 1964). The other was the observation of the microwave background radiation (Penzias and Wilson 1965) 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.

2. The Standard Cosmological Model: Some Critical Issues

The issue related to matter creation is perhaps the most ticklish conceptual issue in standard cosmology. This can be shown by the following line of reasoning. The Hilbert action which leads to the equations of general relativity and which in turn provide the dynamical basis of standard cosmology, is given in standard notation by

$$A = \frac{c^3}{16\pi G} \int_{\mathcal{V}} R \sqrt{-g} d^4 x \quad (1)$$

Here V is the 4-volume of the spacetime region in which the action is defined. The variational principle which leads to the Einstein tensor of relativity, requires the integrand to be well defined with continuous second derivatives with respect to the spacetime coordinates. However, when we solve the cosmological equations based on this action, we hit the big bang event at the cosmic epoch $t = 0$, where (1) breaks down. Thus there is a mathematical inconsistency in the entire procedure which is usually ascribed to the presence of a *spacetime singularity*.

Normally the existence of an inconsistency is taken to rule out the solution via the logic of *reductio ad absurdum*. Here, however, the singularity is dignified to the level of a metaphysical event beyond the scope of physics and mathematics. The physical limitations are shown by the fact that at the breakdown of the action principle, the law of conservation of matter and energy also breaks down. Which is why, the sudden appearance of all matter and energy in the universe remains unexplained. Instead the cosmologist tries to work within the zone $t > 0$, going as close to the singular epoch as the equations permit, but keeping away from it.

The attempt by Gamow and his colleagues to understand the origin of nuclei in terms of nucleosynthesis at the early epochs can be seen in this context. As mentioned earlier, the attempt had a very limited success. In 1967, Robert Wagoner, William Fowler and Fred Hoyle (1967) repeated a calculation originally reported by Gamow, Alpher and Herman. They calculated 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 satisfactorily in agreement with astrophysical observations if the average cosmological density ρ (in g/cm^3) of baryonic matter was related to the radiation temperature T (in Kelvin) by $\rho = 10^{-32} T^3$.

Cosmological theory requires this 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 $2 \times 10^{-31} \text{g/cm}^3$ for the present-day average density of the cosmos. For a comparison, the standard model predicted 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 more dense than this are closed in the topological sense, while those with less density are open.

Although this density was almost two orders of magnitude less than the standard model's closure density, it agreed with galactic astronomer Jan Oort's estimate for the average cosmic density of observable material. The higher "closure" value of about 10^{-29}g/cm^3 given by standard cosmological theory, is explained in terms of nonbaryonic matter that has changed its identity over the years from neutrinos to esoteric "cold-dark matter" particles, perhaps with some remaining admixture of neutrinos. For some of us, 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.

This 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 6×10^{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 4.37×10^{-13} erg/cm³. That is quite close to the observed energy density of the microwave background, namely 4.18×10^{-13} erg/cm³.

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 here at a later stage).

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, and so we are in fact violating the repeated testability criterion of a physical theory.

Ironically, the existence of the microwave background which is claimed as the best evidence for the big bang cosmology, itself prevents direct observations of these very early epochs. For as we try to probe the universe prior to the 'surface of last scattering' the scattering of photons prevents any coherent observations from being made. Thus one has to rely on a string of consistency arguments only in lieu of direct proof for very profound statements about the early universe.

These and other unsatisfactory features led Fred Hoyle, Geoffrey Burbidge and myself to take a fresh look at cosmology and try a new approach.

3. Quasi Steady-State Cosmology

Since 1993, we have been developing an alternative cosmology, beginning from an action principle by which we seek to explain how matter and radiation appeared in the universe (Hoyle, et al 1993). That is to say, the action principle includes the possibility that the world-line of a typical particle can have a beginning. The details involve a scalar field analogous to that which appears in popular inflationary models favored by standard cosmology, and also very similar to the scalar field used to describe creation of matter in the steady state cosmology (Hoyle and Narlikar 1964). As it does in the inflationary models, the scalar field exerts a negative pressure that explains the universal expansion. In our 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.

We regard the creation as being triggered locally in what we call *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, we argue, 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 $10^{26} \text{ cm}^2 / \text{s}$ per gram. But matter rotating about a galactic centre 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 centres 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, we will discuss next 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*'. We outline the important features of this model. For details, see Hoyle, et al (1994, a, b, 1995, 2000)

4. Cosmological Solutions

The spacetime geometry of the quasi-steady state cosmology (QSSC) 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 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 in 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:

$$S(t) = F_Q(t) \cdot \exp(t/P). \quad (2)$$

In the time-dependent scale factor, the parameter Q is the temporal period of the periodic function $F_Q(t)$, 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. For details of these solutions see Sachs, et al (1996).

The quasi steady-state model also has two 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 best fit the observational data are

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

$$S_{\max} / S_{\min} = 9 \text{ and } S(t_0) / S_{\min} = 6. \quad (3)$$

Notice that the oscillations of the scale factor are always within finite limits: in short there is no spacetime singularity.

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 is widely regarded as *tour de force* for the standard model.

5. 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 starlight at *the present epoch* is adequate to give a radiation background of ~ 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 so than the typical spherical grains. These are formed when supernovae make and eject metals in vapour 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^3 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) and Hoyle, et al (2000).

But near an oscillatory maximum, the universe is sufficiently diffuse that such intergalactic particulates 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, on 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° , 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, in our opinion, 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.

6. Origin Of The Light Nuclei

There are more than 320 known isotopes of the elements. In 1957 Geoffrey and Margaret Burbidge, Willy Fowler and Fred Hoyle (1957) showed that, with the

possible exceptions of deuterium, ^3He , ^4He , ^6Li , ^7Li , ^9Be and ^{10}B , ^{11}B , all the isotopes were synthesized by nuclear processes in stellar interiors. Burbidge and Hoyle (1998) have recently reviewed the situation as follows.

The list of eight problematic cases was soon reduced to five, as ^6Li , ^{10}B , and ^{11}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 ^9Be , strongly suggesting that ^9Be was produced in association with the iron in supernovae. Thus the original list of eight light nuclear species that at one time were candidates for association with a hot Big Bang cosmology is now reduced to four. Of these, lithium can possibly be made under stellar circumstances, in view of the finding of lithium rich supergiant stars.

Then we restress the striking fact that the energy density of the microwave background is very close to what we calculate for the production of the observed ^4He abundance solely by hydrogen burning in stars. When all this is put together, we are left with only two of the eight special cases, as they seemed in 1957 - namely deuterium and ^3He .

What is the likelihood, we now ask, that even these last two will turn out to have purely astrophysical origins? ^3He is accumulated in large quantities in dwarf stars whose masses are too small for the isotope to be destroyed by the radiation $^3\text{He} + ^3\text{He} \rightarrow ^4\text{He} + 2p$. There is also a class of earlier-type, more massive stars (including 3 Cen A), in which most of the helium is ^3He . On the $Q \approx 10^{11}$ year time scale of the quasi steady-state cosmology, it seems likely that the cosmic abundance of ^3He (Big Bang nucleosynthesis predicts about one for every ten thousand ^4He nuclei) is to be explained by an escape from stars of these types in stellar winds.

Deuterium, the last survivor from our 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, I think that the deuterium case can reasonably be regarded as uncertain. With all other nuclides (except, of course, ^1H) 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.

7. 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 in his static model of 1917 as unnecessary, suddenly found it a very attractive parameter! 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.

On the other hand, as has been shown by Banerjee, et al (2000), 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. Indeed, for best fit to the data, the optimum value of the adjustable parameter, viz. the whisker density, lies very well in the range required to generate thermalized 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 (see Banerjee and Narlikar 1999). The other test relates to counts of radio sources up to varying levels of flux density. This number-flux density relation can also be closely simulated by the QSSC.

8. The Minicrations Events, Dark Matter And Active Nuclei

In the period 1958-74, 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 clung to the belief 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 or energy". This conjecture was already put forward for some of the great clusters of galaxies by Fritz Zwicky in the 1930s. 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 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, we do have 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 $10^5 M c^2$ where M is the mass of the Sun. 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 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 most 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.

9. Large Scale Structure

The minicreation centres act as nuclei for large scale structure. Imagine that most of the matter creation goes on near the oscillatory minima. Thus to restore 'steady state' from one cycle to next, the decline in density by the factor $\exp[-3Q/P]$ must be made by the creation process. The creation of new galaxies to take the place of old ones must therefore be by a factor

$$f = 1 - \exp[-3Q/P] \quad (4)$$

multiplying the density of the population at the minima. One may therefore assume that in typical creation centres new coherent objects are created and ejected, some of which may act as nuclei of fresh creation later.

Taking these features of the QSSC into consideration, Ali Nayeri, Sunu Engineer, J. V. Narlikar and Fred Hoyle (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 $xN^{-1/3}$, 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. From the work of Nayeri et al (1999), it is clear that the distribution of points soon develops clusters and voids,

typically like that in the real universe. A two-point correlation analysis confirms this visual impression quantitatively. 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.

10. Distinguishing Tests

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 (~ 0.1) *blueshifts*, they can be identified with those from the previous cycle, lying close to the peak of the 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, ~ 40 -50 Gyr old, and as such they cannot be accommodated in the standard model, but will naturally belong to the generation born in 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 we 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 with the debate about the original steady state cosmology.

11. Anomalous Redshifts

I will end with a very fundamental question: *Is Hubble's law obeyed by all extragalactic objects?*

Throughout this discussion we have taken it for granted that the redshift of an extragalactic object is cosmological in origin, i.e., that it is due to the expansion of the universe. Indeed, we may call this assumption the Cosmological Hypothesis (CH). The Hubble diagram on which the CH is based shows a fairly tight $m - z$ relationship for first ranked galaxies in clusters, thus justifying our belief in the CH. However, a corresponding plot for quasars has enormous scatter (Hewitt and Burbidge 1993). Although people discuss the cosmological tests on the basis of CH for quasars as well as galaxies, it is found that in

some cases special efforts are needed to make the CH consistent with data on quasars. These include, apart from the Hubble diagram, the superluminal motion in quasars, rapid variability, the absence of Ly- α absorption trough, etc., which I will not have time to go into here (see, however, Narlikar 1989 for a discussion)

To what extent is the CH valid for quasars? Let us begin with the type of data Stockton (1978) had collected in which quasars and galaxies were found in pairs or groups of close neighbours on the sky. The argument was that if a quasar and a galaxy are found to be within a small angular separation of one another, then very likely they are physical neighbours and according to the CH their redshifts must be nearly equal.

This argument is based on the fact that the quasar population is not a dense one and if we consider an arbitrary galaxy, the probability of finding a quasar projected *by chance* within a small angular separation from it is very small. If the probability is < 0.01 , say, then the null hypothesis of projection by chance is to be rejected. In that case the quasar must be physically close to the galaxy. This was the argument Stockton used.

While Stockton found evidence that in such cases the redshifts of the galaxy and the quasars, z_G and z_Q , say, were nearly the same, there have been data of the other kind also. In two books H.C. Arp (1987, 1998) has described numerous examples where the chance projection hypothesis is rejected but $z_G \ll z_Q$. Over the years four types of such discrepant redshift cases have emerged:

1. There is growing evidence that large redshift quasars are preferentially distributed closer to low redshift bright galaxies .
2. There are alignments and redshift similarities in quasars distributed across bright galaxies.
3. Close pairs or groups of quasars of discrepant redshifts are found more frequently than due to chance projection.
4. There are filaments connecting pairs of galaxies with discrepant redshifts.

It is worth recording that there are continuing additions to the list of anomalous cases. They are not limited to optical and radio sources only, but are also found in X-ray sources, as shown recently by Arp (1998). The reader may find it interesting to go through the controversies surrounding these examples. The supporters of CH like to dismiss all such cases either as observational artefacts or selection effects. Or, they like to argue that the excess number density of quasars near bright galaxies could be due to gravitational lensing. While this criticism or resolution of discrepant data may be valid in some cases, it is hard to see why this should hold in *all* cases.

Another curious effect which was first noticed by G. Burbidge (1968) in the late 1960s concerns the apparent periodicity in the redshifts distribution of quasars. The

periodicity of $\Delta z \cong 0.06$ first found by Burbidge for about seventy QSOs is still present with the population multiplied thirtyfold. What is the cause of this structure in the z -distribution? Various statistical analyses have confirmed that the effect is significant. Another claim, first made by Karlsson (1977), is that $\log(1+z)$ is periodic with a period of 0.206. This also is very puzzling and does not fit into the simple picture of the expanding universe, that we have been working with in this book.

On a much finer scale W. Tifft (1996) has been discovering a redshift periodicity $c\Delta z = 72 \text{ km/s}$ (and also at half this value) for differential redshifts for double galaxies and for galaxies in groups. The data have been refined over the years with accurate 21 cm redshift measurements. If the effect were spurious, it would have disappeared. Instead it has grown stronger and has withstood fairly rigorous statistical analyses.

For a universe regulated by Hubble's law, it is hard to fit in these results. The tendency on the part of the conventional cosmologist is to discount them with the hope that with more complete data they may disappear. At the time of presenting this account the data show no such tendency!

It is probable that the effects are genuine and our reluctance to ignore them also stems from the lack of availability of any reasonable explanation. The explanation may bring in a significant non-cosmological component in the observed redshift z . Thus we should write:

$$1+z = (1+z_C)(1+z_{NC}) \quad (5)$$

The cosmological component z_C obeys Hubble's law while the noncosmological part z_{NC} exhibits the anomalous behavior. What could z_{NC} be due to? There are a few possibilities, none of which is thoroughly tested for full satisfaction:

1. Doppler effect arises from peculiar motions relative to the cosmological rest frame. It is a well known phenomenon in physics.
2. Gravitational redshift arises from compact massive objects, as discussed in general relativity.
3. Spectral coherence discussed by E. Wolf (1986) causes a frequency shift in propagation when light fluctuations in the source are correlated.
4. In the tired light theory a photon of nonzero rest mass loses energy while propagating through space.
5. In the variable mass hypothesis arising from the Machian theory of F. Hoyle and the author (see Narlikar 1977), particles may be created in small and large explosions and those created

more recently will have smaller mass and hence larger redshift.

I am partial to the last alternative as it seems to fit most of the important features of anomalous redshifts. It explains why there are no anomalous blueshifts seen. It reproduces the observed quasar-galaxy configurations and also provides an explanation for the anomalous redshifts of companion galaxies as older stages of quasars in an evolutionary sequence. For details see (Narlikar and Das 1980, Narlikar and Arp 1993).

To what extent can these alternatives provide explanations for the discrepant data? Does matter creation hold the clue to these so-called anomalies? Or, would the discrepancies dwindle away as observations improve? On the other hand, how will theorists explain them if they grow in significance? Clearly these issues have enormous implications for Hubble's law in particular and for cosmology in general.

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