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Chapter 13

Standard Cosmology and Other Possible Universes

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Introduction

The phenomenon of the extragalactic redshift was barely known and the existence of galaxies was a disputed subject at the time Einstein published his epoch-making 1917 seminal paper [22].

Since then, cosmology has evolved in ways unforeseen by this celebrated author at that time under the impetus of these discoveries. To this day, the observable fact of the redshift remains the foremost determining factor of all competing cosmological theories. Its interpretation gives rise to *healthy disagreement* between scientists of diverse breeds.

Amongst several contenders, the so-called Big Bang cosmology, here labelled BBC, has acquired a largely dominant position which justifies calling it "Standard Cosmology" even if it is at odds with the original theory proposed by Einstein. Although its proponents and the media present it as definitive science, a number of other views are put forward by respected scientists and it is the purpose of the present chapter to describe, in addition to the pros and the cons of BBC, the arguments in favour or against a few of the competing hypotheses.

In so doing, we will endeavour to be as objective as brevity allows, avoiding in particular the kind of sarcasm unfortunately so widespread in this area of science which is an eminently arguable subject. Jean-Claude Pecker, a vigilant man, regretfully writes in his excellent book [79, p. 525], one of several recommended readings and a most open minded source of documentation: "There is undoubtedly a sort of intellectual dictatorship of the cosmological establishment, which has its Gospels, its Paradise and its Hell". That being said, the defenders of conventional wisdom, often quite haughty, certainly do not have a monopoly of disrespectful or acrimonious words. In consulting the literature, the reader would be well advised to disregard irrelevant passages of this nature which do not contribute to a better understanding of this fascinating subject.

The competition between cosmological theories after Einstein revolves mostly around their respective ability to account for the observational data relating to three phenomena: 1 – the redshift of electromagnetic radiation from extragalactic objects; 2 – the *cosmic background radiation* (CBR); 3 – the relative *abundances* of light elements in the universe.

However the main challenge is discovering the nature of the extragalactic redshift. What complicates matters is that it would seem to have more than one cause. Sometimes, in the expanding universe theories such as BBC, its explanation is postulated and the theory is built around this postulate; other times, as in *chronometric cosmology* (CC), it is derived from the curvature of space, a second possibility originally contemplated also by Hubble. Still other times, as in some *tired-light* mechanisms, it appears as a consequence of photon collisions. The *Quasi-Steady-State Cosmology* (QSSC) ascribes more than one cause to the redshift. In the *Plasma Universe* of Alfvén an antimatter theory is put forward with some reservations to explain the phenomenon. Halton Arp attributes it to intrinsic properties of matter and the numerous so-called *anomalous redshifts* that he has discovered appear to seriously defy all cosmologies. These findings are also called *discordant redshifts* and they seem to be quite real, despite the denials of most advocates of BBC, and the question remains to what extent they may be statistically significant.

In the same order of ideas, one may wonder about the impact on statistical studies of observations if multiple images of the same object are seen in the night sky, be it in the context of CC or in a variant of BBC in which the cosmological principle is denied giving rise to multiply-connected finite spaces.

Not all aspects of the theories presented are in contradiction with one another. For instance, *plasma cosmology* (PC) appears to the present author essentially compatible with CC except for the flatness and infiniteness of space which seem to be inessential features of PC. The two cosmologies CC and PC may be complementary to a large extent: the first providing kinematics and the second dynamics. The dominant role that electromagnetism plays in the plasma universe and the fact that the Einstein universe is the proper setting for Maxwell's equations, as Segal has shown, suggest a link between these two theories.

Mostly for lack of space, we have left out theories, such as *ultimate theories of everything*, which for the time being appear metaphysical in the sense of having no phenomenological basis, such as the possibility of the existence of parallel universes or of space–time having more than four dimensions. This is not to say that such questions are devoid of meaning or of interest.

The literature being very abundant, we have listed mostly the references that are explicitly referred to. We have marked with asterisks some titles that we consider to be particularly relevant. Also listed are some websites that we think are useful.

1. Greatness and Miseries of the Big Bang Theory: Its Rise and Predictable Fall?

1.1. The Dogmas of the Big Bang Cosmology and the Arguments in Its Favour

"Big Bang" is a disparaging expression coined by an opponent of BBC, Sir Fred Hoyle. The cautious and respectful Jean-Claude Pecker would rather call it "the primeval fireball hypothesis" or "the general explosion" [79, footnote p. 411].

Here are the major propositions of the BBC creed:

- The universe is expanding and this expansion follows Hubble's law which relates linearly the redshift from an extragalactic object to its distance from us.

- Time did not exist before the Big Bang; there is simply no "before". Likewise, space was born with the Big Bang so the general explosion did not take place in pre-existing space [115, p. 272].

Whether space is finite or infinite is still debated amongst BBC supporters. If space is finite, it was born as just a point and one may perhaps say this is where the Big Bang occurred. If space is infinite, it always was since it was generated and so was never small; some say then that the Big Bang occurred everywhere at the same time in that infinite space (Hubert Reeve, p. 10 in [29]). In any case, space is held to be a three-dimensional manifold with no edge. A widespread mistaken belief as to what BBC means is that the universe was once a small three-dimensional ordinary *ball* (as opposed to a three-dimensional *sphere*) and is now a much larger one still expanding i.e. still pushing its edge further away into nowhere.

If space is infinite, some say open or flat, it contains an infinite quantity of matter; there are then infinitely many galaxies by virtue of its homogeneity.

What does "expanding universe" mean? According to a widespread conception, or misconception, of that phrase, it is space itself that is expanding and not the galaxies in it which are flying away from one another in pre-existing space.

For instance Sten Odenwald, an astronomer with Raytheon ITSS, and Rick Fienberg, Editor in Chief of *Sky & Telescope* magazine, declare:

> In Big Bang cosmology, galaxies are located at fixed positions in space. They may perform small dances about these positions in accordance with special relativity and local gravitational fields, but the real 'motion' is in the literal expansion of space between them! This is not a form of movement that any human has ever experienced [77].

In the same vein Wolfgang Rindler writes:

> Note that the cosmological redshift is really an *expansion* effect rather than a *velocity* effect [86, p. 213].

From the mathematical definition of the Friedmann–Lemaître–Robertson–Walker (FLRW) space–times (see Chapter 6) which are used as models of BBC and most other cosmologies, these authors seem to be right.

Or is this indeed the way it is? To the question "How is it possible for space, which is utterly empty, to expand? How can nothing expand?", Nobel Prize physicist and foremost BBC enthusiast Steven Weinberg of the University of Texas replies:

> Good question. The answer is: space does not expand. Cosmologists sometimes talk about expanding space – but they should know better [17, p. 32].

One way of interpreting Weinberg's words is that, according to him, talk about expansion of *space* is no more than metaphorical, the physical fact being the increase in (cosmological) time of the distances between any two galaxies.

Jeffrey R. Weeks expresses his view on this matter this way:

> Houses, people, atoms, and metersticks are not expanding. Planets, stars, and even galaxies are not expanding. Space *is* expanding, and so is the distance between galaxies, but that's about it [115, p. 269].

There are considerable variations in the speed of expansion. It may be much faster than the speed of light as it is supposed to have been in the first zillionth of a second after the Big Bang according to *inflation theory*, a now very popular patch up of the original BBC, which Pecker refers to as the *New Big Bang* [79, p. 486]. After a long sedate period at a much slower pace, it is accelerating again. This last claim, made in 1998 and earlier [33,83], is based on an interpretation of observations of distant supernovae i.e. exploding stars.

In standard BBC, the global topology and geometry of space are determined by the density of the matter it contains in accordance with General Relativity. As a uniform distribution of matter is generally assumed, the local geometry is the same around any point of space and, in particular, space is of constant curvature, i.e. its curvature is the same at all points.

This curvature depends on the density of matter which is to be observationally determined. If this density is above a certain threshold, the curvature is positive, the geometry is elliptic and space is finite; if the density is equal to this dividing value, the curvature is zero and space is Euclidean and hence infinite; if the density is below this value, the curvature is negative, space is again infinite and the geometry is hyperbolic. The ratio of the density to this value is denoted Ω (omega) and called the *density parameter* [80, p. 100].

Conventional BBC affirms the *cosmological principle* also known as the *Copernican principle* asserting the isotropy and hence the homogeneity of the large-scale distribution and composition of matter [32, pp. 570, 617; 69, pp. 714–715; 112]. The exact mathematical definition of this property of space–time is given in [31, pp. 134–136] and, as noted there, it implies the existence of a six-parameter group of isometries of space–time onto itself.

A dissident sect in the BBC chapel challenges this cosmological principle. More about that in a later section.

The *cosmic background radiation* (CBR), also called the *microwave background radiation*, is an echo or afterglow of the Big Bang dating back to the time of *decoupling* of matter and radiation, some hundreds of thousands of years after the Big Bang.

Inflation theory was invented by MIT physicist Alan Guth in the early 1980s to eliminate till then unnoticed or ignored, contradictions in the theory. The *inflationary scenario* resolves three or four problems involving times when the universe was much less than a second old: the '*flatness*' problem, the '*horizon*' problem, the '*smoothness*' problem and the '*entropy*' problem [15, pp. 178–179; 32, pp. 610–612; 30]. A consequence of inflation is that the density parameter Ω is 1 and, as already noted, space is Euclidean. Without inflation the value 1 of the density parameter is very unstable: it rapidly tends to 0 should it be below 1 by any infinitesimal amount; it tends as rapidly to infinity, should it exceed 1, again by any amount. Inflation stabilizes this value 1: should the parameter be any different from 1 one way or the other, it would be brought back to that value in no time [46, pp. 34, 158, 159, 165; 30].

No data whatsoever exists to corroborate this inflation hypothesis. The notorious astrophysicist P.J.E. Peebles declares: "But inflation is not tested, and it is not easy to see how it could be falsified, so it is not part of the standard model [of BBC]" [80, p. 7].

The long decried cosmological constant Λ (lambda) first introduced by Einstein in 1917 makes a comeback in the 1990's [40,39]; it is needed to resolve the universe age problem arising from the fact that some stars are found to be older than the universe if the constant is nil. Assuming it to be 0 and upholding the cosmological principle, the global topology of space i.e. its infinite or finite character is determined by the density of matter as already noted: if there is enough matter, space is closed and the expansion will reverse itself and lead to a big crunch. Otherwise the expansion will continue forever. However, if lambda is nonzero, as some revisionist BBC supporters are now claiming, no such conclusion can be drawn [31, pp. 137, 139].

If moreover the cosmological principle is downgraded from a global to a local principle, the infinite or finite character of space becomes independent of the density of matter though the fate of the universe is presumably determined as before. But we are anticipating on a later section of this chapter.

All matter was created at the time of the Big Bang. The parameter η (eta), the universal ratio of nucleons to photons, has been restricted to a narrow range on the basis of the *observed abundances* of the light chemical elements in the universe. This accomplishment is held to be one of the three main "proofs" establishing BBC, the other two being the claimed empirically verified Hubble law governing the redshift and the existence of the CBR conveniently interpreted.

1.2. The Problems with BBC

Perhaps the most decisive assault on BBC is the large set of rigorous statistical studies of Irving Ezra Segal and J.F. Nicoll of the *Institute for Defense Analysis* in Alexandria, VA, USA ([90,97,93,98] and references therein) and also of V.S. Troitsky[1] [108,107] based on all available astronomical data which show that the distance-redshift relation is not linear but quadratic. This goes to the root of the problem as the linear law, a direct consequence of the expanding universe hypothesis, represents its principal empirically falsifiable implication. Various attacks on these studies have all been sharply responded to.

The hypothesis of *evolution* of galaxies and quasars, another consequence of BBC, is as well shattered by the same kind of statistical analyses which at the same time establish the chronometric cosmology (CC) of Segal (to be discussed in the next section) and which is exempt of any adjustable parameter. Followers of the *evolution* hypothesis use whole adjustable functions to demonstrate its existence whereas the CC hypothesis of no evolution fits the data just as well, with no parameters entering the CC formulae.

To the question; "Does the observable universe show traces of evolution?", Pecker replies: "… the statistical data are no more than suggestive. They are inconclusive in favour of some evolution, within the range of measured z" [79, p. 474].

The proliferation of adjustable parameters in BBC flies in the face of the canons of genuine scientific knowledge. Aside from the deceleration parameter, now turned into an acceleration parameter, the density parameter, the Hubble constant (which, perhaps as other 'constants' may vary with time), and now the cosmological constant, a whole array of parameters is introduced about the evolution of galaxy and quasar populations since the Big Bang to account for the redshift and luminosity data for distant objects. Other parameters are needed for the calculations of the abundances of light chemical elements.

About this last panoply of parameters, Geoffrey Burbidge and his companions write in [14, p. 39]:

> Supporters of BBC gain for themselves a large bag of free parameters that can subsequently be tuned as the occasion may require. […] We do not think science should be done that way.

[1] V.S. Troitsky died on 5 June 1996. He was from the *Radiophysical Research Institute* N. Novgorod, Russia.

Moreover, the long elusive Hubble constant, the recuperated cosmological constant and the deceleration parameter now become not only unknown but unrestricted unknown functions of time. For instance, Lawrence M. Krauss, an astrophysicist from Case Western University, speaking of the cosmological constant, writes [39, p. 59]: "It might not in fact be constant." Krauss speculates further about the vagaries of the expansion itself ([39, p. 58]): "Perhaps the universe is just now entering a new era of inflation, one that may eventually come to an end."

A theory with so much built-in freedom escapes refutation and has little predictive power if any.

In 1989, the editor of the prestigious weekly science periodical, *Nature*, John Maddox, wrote in an editorial entitled, "Down with the Big Bang," [59]: "Apart from being philosophically unacceptable, the Big-Bang is an over-simple view of how the Universe began, and it is unlikely to survive the decade ahead." (!)

BBC *needlessly* forces our minds to make an 'agonizing reappraisal' of our fundamental ways of thinking. Apart from having to adapt to hard-to-swallow notions such as there being no time nor space before the Big Bang our brains have to renounce asking questions such as "What does space expand into?" which become simply inadmissible [80, p. 6]. Such mental exercises should be entertained only after less dramatic hypotheses have been exhausted.

One problem with inflation is that the observational value of the density parameter is considerably below 1. Hence the *dark matter problem:* where is the *missing mass*? If, on the other hand, one renounces inflation, one has to live with the several problems that it resolves and which plague BBC.

Big Bang cosmology requires that all the matter in the observable universe be created in one single moment occurring 10^{-36} second after the Big Bang itself [15, p. 107]. Yet Einstein's well-known equation expressing the equivalence of matter and energy suggests otherwise (and see §3.2 of this chapter). Other cosmologies assert the possibility of converting energy into matter or are compatible with this.

The CBR is not uniquely indicative of a Big Bang, as claimed by BBC. All the other cosmologies can explain it just as well.

For instance, even before any Big Bang ideas, a theoretical prediction of the existence of such a radiation had already been made in 1953–1954, eleven years before its detection, by E. Findlay-Freundlich and Max Born on the basis of a stationary universe. In his famous 1926 book [21], Sir Arthur Eddington calculated the minimum temperature any body in space would cool to, given that it is immersed in the radiation of distant starlight. With no adjustable parameters, he obtained 3 K, later refined to 2.8 K by E. Regener.

The famous physicist Walther Nernst (1864–1941) who received the Nobel Prize in Chemistry in 1920 for his third law of thermodynamics (1906) attempted to compute the temperature of extragalactic space in 1938. He found the lower value of 0.75 K. The works of Eddington, Regener and Nernst make essential use of Stefan–Boltzmann's law, which is characteristic of a black body radiation as that of the CBR at 2.7 K [12].

It is argued that there is just not enough time in the less than 20 billion years since decoupling, the time of separation of matter and radiation, to form the large-scale structure of the universe, given the measurable maximum speeds of galaxies and the size of the superclusters of galaxies and hence the distance matter would have had to travel [46, pp. 23, 25, 28]. BBC man Edward L. Wright [123] objects to this by arguing that distances were smaller in the past by virtue of expansion and therefore less time was needed.

Standard BBC and some other cosmologies assume homogeneity in the distribution and composition of matter in the universe. About this Pecker has this to say [79, p. 462]: "One of the a priori principles of mathematical cosmology is the homogeneity of the Universe. The evidence is opposite to that principle." French astronomer Gérard de Vaucouleurs (1918–1996) describes the distribution of matter in the universe as hierarchical and fractal rather than homogeneous [79, pp. 412, 463, 464]. Pecker writes moreover:

> "Actually, the larger the volume in which density is measured, the smaller is that density. [. . .] Hence the usual value of this density has to be looked at with the utmost care and suspicion" [79, pp. 463, 465].

An abundant literature does exist on the fractal structure of the distribution of matter. Some writers, while recognising this, nevertheless defend its large-scale smoothness [120].

Just as Einstein did in his original 1917 paper, BBC completely ignores electromagnetism in its *fluid of galaxies* idealisation of the content of the universe. For instance, one reads in the textbook [69, p. 712]: "The magnetic fields [. . .] are unimportant for large-scale cosmology, except perhaps very near the 'Big Bang beginning' of the universe." In [31, p. 70], some attention is paid to electric charge which is later left out of the picture [31, p. 136], where the energy-momentum tensor to be used is that of a fluid defined solely by two functions of time: the energy density and the pressure of this gas of galaxies.

Conveying what would seem to be the majority view amongst BBC advocates, Jeremiah Ostriker of Princeton University comments [46, p. 53]: "There is no observational evidence that I know of that indicates electric and magnetic forces are important on cosmological scales."

Segal declares his considerable skepticism about the extrapolation of General Relativity from a theory of gravitation valid on the galactic scale to one on which the dynamics of the entire universe must be based in [95, p. 189], where he adds

> Probably still less justified physically is the application of general relativistic hydrodynamics to extragalactic questions such as the mass density and the stability of the entire Cosmos. The approximation of the distribution of galaxies by a fluid is quite uncontrolled and open-ended; at best, conclusions drawn in this way are merely suggestive.

BBC devotees themselves are not so sure about their calculations of the *primordial abundances* of chemical light elements. For instance, Gary Steigman of Ohio State University says [105, p. 312]:

> Abundances are not *observed*. Abundances are *derived* from the observational data, often following a long and tortuous path involving theory. [. . .] Errors (or uncertainties), often systematic, may be introduced at many steps in the overall process of deriving abundances from observational data. Furthermore we are here concerned with primordial abundances. Even if present day universal abundances were known to arbitrary accuracy (which they are not!), we still would have to employ theory and observation to extrapolate back to obtain primordial (or at least pregalactic) abundances. Additional errors (uncertainties) are surely introduced here too.

Now listen to N. Yu Gnedin and Jeremiah Ostriker, who are also Big Bang supporters [27]:

> Light element nucleosynthesis has been a central pillar supporting the standard FLRW hot Big Bang cosmological model. [. . .] But there are several confusing and apparently inconsistent elements in the canonical picture which have led to 'patches' which are quite ad hoc and are accepted only because of our familiarity with them and our basic belief that the underlying standard model is accurate.

Readers are referred to the website [123] of astronomer Edward L. Wright from UCLA, a steadfast defender of BBC, to read contrary views on several of the above criticisms.

2. Einstein Static Spherical Universe Revisited: The Chronometric Cosmology of Mathematician Irving Ezra Segal

2.1. The Causality Relation

Irving Ezra Segal, who died on August 30, 1998 at age 79, was an MIT professor of mathematics who thought that the universe is exactly as Albert Einstein had first suggested in 1917: an eternal static three-dimensional sphere. His *chronometric cosmology* takes Special Relativity (SR) for granted but is largely unrelated to General Relativity (GR) about which Segal expresses reservations as a foundation for cosmology.[2]

Space–time defined as the totality of all events – past, present and future – is, before anything else, a partially ordered set: the relation $p < q$ between two events means that p precedes q. This relation, known as the relation of *causality*, of *temporal precedence*, or of *anteriority*, is the most immediate observational data. It conceptually and psychologically precedes the measurement of distances and duration, and is independent of any observer.

This innocuous observation is indeed the starting point of the cosmology of mathematician Segal which he calls *chronometric cosmology* (CC). The FLRW space–times are all endowed with such a causality relation, which derives from their time-oriented Lorentzian metrics. Indeed, such a metric defines at each point, i.e. each event p, a future cone in the tangent space at that point. An event p *temporally precedes* an event q if there exists an oriented curve going from p to q at every point of which the forward pointing tangent belongs to the future cone at that point. Such a relation is well known in Minkowski space–time and determines its ordinary Lorentzian metric to within a constant strictly positive factor. This latter fact is a nontrivial but fundamental theorem established in 1953 by the Russian mathematicians A.D. Alexandrov and V.V. Ovchinnikova and rediscovered a decade later by E.C. Zeeman. It entails that causality preserving maps between FLRW spaces are the same as conformal maps.[3]

Minkowski space–time (M) and the Einstein universe (EU) are two such FLRW space–times. The latter has the distinguishing property that all others can be imbedded into it by essentially unique causality-preserving maps, though the metric of time or space, and the factorisation of space–time into time and space, may not be preserved by such imbeddings. In particular, topologically, space in the imbedded space–time may or may not be compact. This property bestows on EU the name of *universal cosmos*. To a

[2] Reference [28] lists all Irving Ezra Segal's publications.

[3] A clear and detailed exposition of it appears in Gregory L. Naber's excellent book [72, pp. 64–74].

mathematician's mind, this fact alone gives EU a very special status and calls it to his or her attention. But admittedly, this may leave most astrophysicists indifferent.

These two models M and EU are related to each other somehow just as the complex plane is related to the Riemann sphere. On the one hand M is causally embedded into EU by a relativistic generalization of stereographic projection, and on the other hand it is tangent to EU at the point of observation, as is the case for any FLRW space–time, or, more generally, for any Lorentzian manifold. We will come back to this point.

Amongst several other distinguishing properties of EU, probably more physically relevant, one has to do with Maxwell's equations. These equations governing light and, more generally, all electromagnetic radiation, which is basically all that is observable in large scale astronomy, are defined primarily in Minkowski space–time M but they extend uniquely, as well as their solutions of finite Minkowskian energy, to the larger universe EU into which M is causally immersed. This mathematical fact designates EU as the proper arena for the interpretation of electromagnetic phenomena.

To our knowledge these properties of EU were unfamiliar to Einstein himself who arrived at EU by an altogether different route related to his *General Relativity* (GR) which, according to some [26, pp. 7, 373, 393, 395] is a misnomer for what should be known only as (Einstein's) *Theory of Gravitation*.

In Segal's opinion, the Einstein universe and Minkowski space–time are the only two space–times satisfying general conditions embodying three fundamental physical principles: the isotropy and global homogeneity of space, i.e. the absence of a preferred direction at any point of space and the absence of a preferred point in space; second, the "principle of inertia", i.e. the statement that there is no preferred timelike direction, which means the equivalence between observers in relative motion at the same point; and third, the possibility to *globally* factor space–time as *time* × *space* and *temporal homogeneity* with respect to this factorization. This is to be understood as requiring not only the absence of a preferred moment on the time axis, but also that time translations with respect to this factorization make up a group of conformal or causal automorphisms of space–time, the *temporal group* belonging to this factorization. The infinitesimal generator of this group is conventionally identified with the energy, thus giving rise to energy conservation laws both in Minkowski and Einstein space–times.[4]

Alexander Levichev from Boston University and the Sobolev Institute of Mathematics in Novosibirsk, a foremost defender of chronometry, calls CC "the crowning accomplishment of special relativity" in the opening paragraph of a paper [50] which remains the best concise introduction to the mathematics of CC.

2.2. *The Main Tenets of Chronometric Cosmology*

In this theory, the universe is not expanding and is eternal in both directions.

Space is a three-dimensional sphere of fixed radius.[5]

[4]Segal repeatedly claims (beginning in [102, pp. 53, 58]) that de Sitter space–time fails to satisfy the third condition. Though de Sitter space–time is homeomorphic to the product of the real line with a three-sphere it is not *globally* factorizable as *time* × *space* in the above sense. Thereby it admits, in Segal's view, no natural definition of energy. This is in spite of the fact that its isometry group is of dimension 10 (which is the dimension of the Poincaré group and hence the maximal number compatible with general relativity) enabling that many conservation laws in the ordinary sense.

[5]The reader is referred to Chapter 6 for a discussion of the three-dimensional sphere also known as the hypersphere.

The theory predicts the redshift phenomenon in EU but with a quadratic law for small distances instead of the linear Hubble law.

CC is a purely kinematical theory; it offers no specific dynamics of the universe though it is essentially compatible with ideas of some other cosmologies in that respect.

For instance, the treatment of nucleosynthesis is similar in CC and in BBC to first order:

> The difference is only that a stochastic sequence of mini Bangs, associated with, e.g.: the formation of galaxy clusters, replaces the unique Big Bang. Cluster formation would be expected to be accompanied by extremely high temperatures, which, as in BBC, would be productive of light elements [103, p. 323].

The idea of a series of '*minibangs*' replacing the single Big Bang is also put forward by Narlikar [74, p. 29] and is also found in the plasma universe [46, p. 217] as well as in Arp's cosmology.

However, CC has no need for dark matter, inflation or other scenarios found in BBC. The matter density in the universe which in BBC plays a major role in determining the shape of space is irrelevant in CC.

Homogeneity and isotropy in CC are postulated only for an empty space. No homogeneous or isotropic distribution of matter is ever asserted. For the phenomenological justification of CC, *luminosity uniformity* (LU) but no *spatial uniformity* (SU) in the distribution of matter in space is postulated. LU states that the intrinsic luminosity of objects is statistically independent of the distance, i.e. of the redshift. This means the absence of evolution of the statistical characteristic of the population of galaxies. This is contrary to the case in BBC where one talks of largely unknown statistical evolution since the Big Bang. Of course individual objects do evolve.

In everyday experience, Euclidean geometry is used. Euclidean space is homogeneous and isotropic. No one claims that these geometrical properties belong to the distribution of matter in space.

Ever since the advent of GR, a widely held belief is that the global geometry and topology of space, including its finiteness or infiniteness, is determined by its energetic content, i.e. the matter and the energy it contains. In CC, the energetic content determines at best only a preferred factorisation of space–time as a product of '*space*' with '*time*' which in turn determines a Lorentzian metric on space–time. Unlike what is the case in Minkowski space–time where there is a unique Lorentzian metric, in EU, there is one for each such factorisation. However, time is eternal and space is a three-sphere of a fixed radius which is the same radius in all such factorisations. But, as is the case in ordinary special relativity, CC pays no attention to matter to begin with, and the Einstein universe makes its appearance quite independently of considerations about gravity contrary to what was the case in Einstein seminal cosmological 1917 paper [22].

As to the cosmic background radiation, Segal writes:

> The observed blackbody form of the cosmic microwave background is simply the most likely disposition of remnants of light on a purely random basis, assuming the classic principle of the conservation of energy, and is not at all uniquely indicative of a Big Bang.

As Jean-Claude Pecker says in [79, p. 511], similar views are often expressed in an infinite-eternal universe which makes the CBR result from an equilibrium between photons and the rest. For instance, Burbidge, Hoyle and Narlikar as well as Arp have comparable explanations of the CBR.

According to CC, the redshift–distance relation is quadratic rather than linear for small redshifts and the theory specifies a formula valid for all distances, as we shall see next.

2.3. *The Chronometric Redshift Theory*

According to CC, Einstein's model EU is the correct one to understand the universe as a whole, except that there are two kinds of time: a cosmic (or Einstein) time t, and a local (or Minkowski) time x_0.

This two-time situation arises from the essentially uniquely defined conformal immersion of Minkowski space $M = R \times R^3$ (the Cartesian product of a time axis with three-dimensional Euclidean space) into $EU = R \times S^3$ (the Cartesian product of a time axis with a three-sphere). This immersion is a relativistic variant of stereographic projection. Minkowski space M can be thought of as being tangent to EU just as the complex plane is tangent to the Riemann sphere. This immersion of M into EU preserves causality but does not preserve the time coordinate nor the space coordinate in the factorizations of these space–times as a Cartesian product of 'time' with 'space'.

In Segal's words,

> The key point is that time and its conjugate variable, energy, are fundamentally different in the *EU* from the conventional time and energy in the local flat Minkowski space *M* that approximates the *EU* at the point of observation.

Simply put, Einstein's cosmic time t is the "real" one, whereas Minkowski's time is only an approximation of t. Which time and space coordinates, those of EU or those of M, are actually measured in observations is empirically immaterial, since the two differ by unobservably small amounts except for extragalactic observations.

Using appropriate units such that the speed of light $c = 1$ and denoting by r the radius of the three-sphere, Einstein's and Minkowski's time coordinates are related by the equation

$$x_0 = 2r \tan\left(\frac{t}{2r}\right) \tag{1}$$

which may be called the chronometric two-times formula, from which the relation

$$z = \tan^2\left(\frac{t}{2r}\right) \tag{2}$$

of an observed redshift z to time of propagation t, or equivalently, geodesic distance on the 3-sphere, may be derived essentially by simple differentiation.

Assuming formula (1), we derive formula (2). For a wave of frequency ν and of observed redshifted smaller frequency ν', the redshift z is defined by the quotient $(\nu - \nu')/\nu'$. Letting dt stand for a small interval of cosmic time, dx_0 for the corresponding small interval of Minkowskian time and f for the number of oscillations during that duration, we have, using formula (1), that

$$\frac{\nu}{\nu'} = \frac{f/dt}{f/dx_0} = \frac{dx_0}{dt},$$

$$z = \frac{\nu - \nu''}{\nu'} = \frac{\nu}{\nu'} - 1 = \frac{dx_0}{dt} - 1 = \sec^2\left(\frac{t}{2r}\right) - 1 = \tan^2\left(\frac{t}{2r}\right).$$

Equation (2), called the *chronometric redshift formula*, may also be derived [102,103] in (and above) the observable frequency range by a rigorous analysis based on Maxwell's equations. It follows from this analysis that a free photon will experience a redshift when propagated over a very long period according to Einstein time.

Equation (1) implies that as t varies from $-\pi r$ to $+\pi r$, ordinary time goes from minus infinity to plus infinity. Hence, eternity (past and future) in the ordinary sense corresponds to a finite interval of cosmic time, which cosmic time t, nevertheless, varies over the whole real line. As for Eq. (2), it reveals that for small values of t (or, equivalently, of the distance), the redshift varies as the square of t, in contradiction with Hubble's law, which is linear. From (2) we also see that as r tends to infinity, z tends to 0. Hence, as envisaged as a possibility by Hubble himself, the curvature of *space* is the reason for the cosmic redshift in CC.

If the choice of units is completed in such a way that the fixed radius of space r is 1, in addition to the choice $c = 1$ made earlier, which makes t equal to the distance d, then the chronometric redshift–distance relation (2) is seen to be entirely parameter-free and is thus quite vulnerable. This is quite unlike the similar relation in BBC which involves the deceleration parameter, the cosmological constant, the curvature parameter and the present radius of space as parameters.[6]

As Lerner points out at the very end of his book [46] the importance, for cosmology, and for physics more generally, of having the correct relation between the extragalactic redshift and the distance cannot be overemphasized.

2.4. Elementary Particles in Chronometric Theory

Segal's chronometric theory not only covers cosmology, it also includes a successful theory of fundamental particles based on the Einstein universe instead of on the Minkowski space–time. As a matter of fact, the chronometric theory was originally developed for elementary particle applications.

In the chronometric elementary particle theory, each particle, including the photon, has an unobservably small, but theoretically very important, "*bare*" mass, in addition to a considerably more substantial empirically observed "*clothed*" or *gravitational*, or else *Machian*, mass deriving from its interactions throughout the universe. The two together make up the *inertial mass* [91, p. 853; 101, p. 175]. This is not unlike the Narlikar–Arp *variable mass hypothesis* to be mentioned in a subsequent section.

In a forthcoming paper [49], Levichev writes:

> In Segal's chronometry, the entire list of known particles is derived mathematically. One chronometric particle (the "exon") has not yet been experimentally identified [94].

2.5. Observational Tests of Chronometric Cosmology

Using a sophisticated bootstrap statistical technique that they call ROBUST, which takes into account the so-called "observational cutoff bias" making faraway celestial objects less likely to be observed than closer ones since they are apparently less luminous and hence harder to 'see', Segal and collaborators have demonstrated in several articles that the quadratic redshift–distance law predicted by CC fits all available experimental data

[6] See, for instance, Eq. (29.16), p. 781 coupled with (29.2), p. 772 in [69].

very well whereas the Hubble law fails miserably on every count. The more general CC redshift–distance formula valid for all distances is also experimentally confirmed without appealing to an hypothetical largely unknown evolution as in BBC.

In his address to the Colloquium on Physical Cosmology, sponsored by the National Academy of Sciences of the USA in March 1992, Segal stated:

> The good news is that there is a simple redshift–distance relation that appears consistent with observations in complete objectively defined samples in the infrared and X-ray wave bands, as well as the optical. The bad news is that at low redshifts it doesn't at all resemble the Hubble Law, which appears simply irreconcilable with these observations.

Quite independently of Segal, the Russian author, V.S. Troitsky, has established a quadratic redshift–distance law in a 1996 paper [107, pp. 94, 105] on the basis of a statistical analysis of a very considerable sample of more than 73197 galaxies.

2.6. *About Supernovae, 'Time Dilation' and 'Dark Energy'*

In 1996, acknowledging that widely accepted experimental proof of the universal expansion hypothesis was lacking, B. Leibundgut *et al.* claim [45] that the observation of a particular supernova provides strong evidence for this assumption and is incompatible with a static universe or with tired-light theories. The evidence, held to be a "clear vindication of an expanding universe", consists in observing that the light curve of this distant supernova is stretched by a factor of $1 + z$ as, they say in their abstract, is "prescribed by cosmological expansion". This means that the rise and fall of the light intensity of that distant supernova is over a longer time span than similar events in nearby supernovae. A year later this interpretation of the observation has been challenged both by Segal on the one hand and by Narlikar and Arp on the other from the standpoints of their respective theories.

Segal [90][7] shows that the time dilation factor $1 + z$ is also *prescribed* in the context of chronometric cosmology. This dilation effect in CC is essentially obtained by simple differentiation of our formula (1) which expresses Minkowskian time in terms of cosmic time, or equivalently the cosmic distance ρ on the 3-sphere of radius r as we assume the velocity of light c to be 1, while taking our formula (2) into account. Indeed, one readily obtains

$$\frac{\partial x_0}{\partial t} = \sec^2\left(\frac{t}{2r}\right) = 1 + \tan^2\left(\frac{t}{2r}\right) = 1 + z. \tag{2.1}$$

In the same issue of the *Astrophysical Journal*, Narlikar and Arp [75] claim to establish the same dilation factor $1 + z$ in the context of their "variable mass hypothesis".

In 2001, Leibundgut acknowledges these contradictory views. He writes on p. 79 of [44]: "The SN [= supernova] result, however, has also been interpreted in other, nonexpanding cosmologies [75,90]." And on p. 89:

> In a quasi-steady state cosmology, a combination of acceleration due to the formation of matter and the particular, gray dust proposed by Aguirre (1999b) can reproduce the SN observa-

[7] A misprint occurs in (the first part of) formula (2) of [90]: "$\cos t$" there should be replaced by "1" as in formula (3) of the same paper. So corrected, that formula (2) reads $x_0 = 2\sin t/(1 + \cos t)$ and becomes equivalent to our formula (1) with $r = 1 = c$ and $t = \rho$.

tions (Banerjee et al. 2000). Because this world model has an oscillating scale parameter, the SN result would not be extraordinary in such a framework.

The observed '*time dilation*' phenomenon concerning distant supernovae is the root of the *accelerating universe hypothesis* [44, p. 67].

The belief in an accelerating universe, often attributed to some 'dark energy' related to a nonzero cosmological constant, stems from the discovery that distant supernovae are less luminous than they are expected to be on the basis of their measured redshifts as interpreted in the framework of BBC.

Robert P. Kirshner from the Harvard-Smithsonian Center for Astrophysics, in Cambridge, USA explains it thus:

> If the universe had been decelerating – in the way it would if it contained the closure density of matter, that is, if $\Omega_m = 1$ – then the light emitted at redshift $z = 0.5$ by a SN Ia would not have travelled as far, compared with a situation where the universe had been coasting at a constant rate – characteristic of an empty universe, where $\Omega_m = 0$. For a universe with $\Omega_m = 1$, the flux from the distant supernova therefore would be about 25% brighter. But the distant supernovae are not brighter than expected in a coasting universe, they are dimmer. For this to happen, the universe must be accelerating while the light from the supernova is in transit to our observatories [37, p. 4226].

Adam G. Riess from the Space Telescope Science Institute in Baltimore, puts it somewhat differently:

> A more illuminating way to quantify the evidence for an accelerating universe is to consider how the SN Ia distances depart from decelerating or 'coasting' models. The average high-redshift SN Ia is 0.19 mag dimmer or about 10% farther than expected for a universe with no cosmological constant and negligible matter [85, p. 1287].

More recently the findings of the Wilkinson Microwave Anisotropy Probe (WMAP) [136] (a NASA satellite whose mission is measuring the temperature of the CBR over the full sky) are thought to confirm the existence of this 'dark energy' which together with 'hot' or 'cold dark matter' would make up most of the material in the universe. The influential *Science* magazine pompously saluted this discovery as the Number 1 breakthrough of the year in December 2003 [104].

However, several articles such as '*Things fall apart*' [121], cite the work of a number of unconvinced cosmologists who busy themselves pouring cold water on hot or cold dark matter and predicting a dark future for dark energy.

It is not suggested that the '*accelerating universe*' implies the speed of expansion has always been increasing. For instance Riess et al write in [84, Sect. 1.1]:

> If the cosmological acceleration inferred from SNe Ia is real, it commenced rather recently, at $0.5 < z < 1$. Beyond these redshifts, the universe was more compact and the attraction of matter dominated the repulsion of dark energy. At $z > 1$, the expansion of the universe should have been decelerating.

An accelerating universe means that the Hubble 'constant' is in fact a decreasing function of the distance at least for the values of z in the interval $0.5 < z < 1$. This would seem to be in contradiction with chronometric cosmology as one easily computes, by differentiating formula (2) with respect to t, that cz, which may be considered as the *speed of expansion* in CC, is an increasing function of t (which is the same as the distance with $c = 1$).

In any case, the following passage from a 1997 paper by Segal [90, pp. 70–71] leaves little doubt as to what he thought, and presumably would still think, of the observation of supernovae as a basis for establishing Hubble's law:

> Today there is a new wave of claims for the validation of the Hubble law, on the basis of observations of another quite non-generic type of object, namely supernovae. Bold, if not somewhat disingenuous, claims for "measurement" of the distances to supernovae are made, notwithstanding that the crucial difficulty in extragalactic astronomy is that the distance to a source can never be measured in a truly model-independent way. The directly observable content of the Hubble law in no way involves putative distances, but is rather to the effect that the apparent magnitude m and the redshift z are related by the equation $m = 5 \log z + M$, where M is a random variable that is independent of z. The 'distances' of supernovae are, like the 'standard candle' character of the Bright Cluster Galaxies, theorised rather than observed. Because of their transience, irregularity, scarcity and difficulty of classification into appropriate types, the use of supernovae as primary sample objects for cosmological testing would probably serve to moot the redshift–distance relation indefinitely.

The next year, Segal wrote in a joint paper with Nicoll submitted shortly before his sudden death:

> More recently, the linear law has been derived from observations on large-redshift supernovae of type Ia. It is now acknowledged that the peak luminosities of these objects have a substantial dispersion and that an apparent linear law requires extensive model-dependent corrections [98, p. 510].

This last declaration is well supported in 2001 by Leibundgut, a staunch advocate of the accelerating universe hypothesis:

> The observational characteristics of nearby Sne Ia show some differences from event to event. Despite their considerable range in observed peak luminosity, they can be normalized by their light-curve shape. Through this normalization, SNe Ia can be used as exquisite distance indicators. [...] SNe Ia have long been proposed as good distance indicators for cosmology, first through their standard candle character, i.e., identical peak luminosity, and later normalized by corrections from light-curve shapes. [...] Different methods for the light-curve shape corrections, however, do not compare well with each other; significant differences in the implementations of the corrections are found [44, pp. 67–69].

2.7. Phantom Galaxies?

Could it be that the night sky were a family album of the living and the dead celestial objects, each of them being depicted a large number of times? There would then be far fewer objects than there appears to be.

As we will see later, this view is now defended by a small group of Big Bang supporters. It would seem that this possibility arises in the context of chronometric cosmology as well.

Already in 1920, Hermann Weyl wrote [116, p. 278]:

> If the world is closed, spatially, it becomes possible for an observer to see several pictures of one and the same star. These depict the star at epochs separated by enormous intervals of time (during which light travels once entirely round the world).

In 1974, Segal wrote:

In view of the apparent transparency of intergalactic space, the residual radiation should typically make many circuits of space before being ultimately absorbed by matter.

The following excerpt from a 1995 paper by Segal and Zhou seems to imply that this theoretical possibility is in fact a prediction of CC which nevertheless has not been explicitly stated so far. Indeed in the concluding paragraph of [103] one reads:

Finally, the transparency of cosmic space implies that photons in the Einstein universe EU will typically make many circuits of space (i.e. of the 3-sphere) before being absorbed or undergoing interaction. A free photon will be infinitely redshifted at the antipode of S^3 to its point P of emission, but on returning to P it will be in its original state, as a consequence of the periodicity of free photon wave function in EU.

2.8. *Objections to CC*

On the whole, CC has been ignored or despised by mainstream cosmologists and by some others as well.

But, disregarding the often inappropriate rhetoric on more than one side, I do not know of any objection to CC, from anybody, that has not been answered in print, to my mind satisfactorily, by Segal except for a somewhat astonishing but minor blemish of little consequence found in one of his numerous papers [19].

We have provided in [18] an answer to a 1997 critical study of CC on the basis of a sharp and extensive rebuttal found in an unpublished manuscript submitted by Segal and his collaborator Jeff Nicoll, but which was rejected by the *Astrophysical Journal* in 1998, shortly before Segal's death.

It is sometimes argued that CC is a purely kinematical theory that says nothing of the dynamics of the universe. True, but this only shows that the theory is incomplete and not that it is wrong. It may incorporate, for instance, the essential elements of the *Plasma Universe* to be discussed in a later section.

The most serious challenge still facing CC, shared by other cosmologies, is posed by Arp's discordant redshifts to be discussed in the next section.

3. Is the Redshift a Distance Indicator? The Anomalous Redshifts of Halton Arp

3.1. *Arp's Enigmatic Observational Discoveries*

A distinguished observational astronomer, Halton Arp was for 29 years a staff member of the observatories known originally as the Mt. Wilson and Palomar Observatories. He is currently at the Max-Planck-Institute in Munich. His 1998 book *Seeing Red* [11] and also his 1987 book *Quasars, Redshifts and Controversies* [10] expound the details of his findings and tell the vicissitudes of his scientific life and publications. His most recent book is a *Catalogue of Discordant Redshift Associations* [8].

The most important thing in what Arp contends is that the redshift cannot be a distance indicator as he lists numerous "discordant redshifts", also called *anomalous redshifts*, consisting of some celestial objects having very different redshifts which must nevertheless be at the same distance from us since Arp argues that they are obviously in interaction.

Arp's observations have generally been disregarded or denied by mainstream cosmologists.

In Arp's view, there is no expansion of the universe, extragalactic redshifts are interpreted predominantly as an intrinsic property of matter measuring its age, i.e. the time elapsed since its creation.

Arp shares with Jayant V. Narlikar [73] a belief in the *variable mass hypothesis*, which asserts that all particle masses uniformly scale with epoch, and which he claims "fits the data better than the Big Bang mantra". He sees in it the reason why the nonexpanding universe does not collapse [11, pp. 231–233].

According to Arp, there is continuous creation of matter; meaning the transformation of previously existing mass–energy. This is suggested by the many ejections of quasars from small dense nuclei of active galaxies that we can see. The quantized properties of the redshifts are linked with the properties of young matter as it is expelled from galaxies by old dense matter [11, p. 228; 79, p. 508].

The younger the object, the larger the redshift [11, p. 77]. Arp suggests that perhaps younger matter emits weaker photons [32, p. 467]. Matter is born with high redshift and *zero* mass. The former decreases and the latter increases (the *variable mass* hypothesis) with the passage of time as the new-born particles interact with an ever larger portion of the universe [11, pp. 108, 238].

These ejected quasars typically move outward with speeds of from a few tenths of c to the speed of light. They move out in pairs in opposite directions along the rotation axis of the parent galaxy. "Opposite ejection of extragalactic material is a ubiquitous process that operates on all scales". But where Arp sees ejections, others see collisions and mergers [11, pp. 245, 191, 71, 72].

In Arp's view, quasars are low luminosity recently created objects and can be quite nearby. This is the opposite of what they are in BBC: far away very luminous objects having existed in the young universe [11, p. 190].

According to Arp, the CBR is formed in the static intergalactic space and has been in equilibrium for billions and billions of years [79, p. 509]. Contrary to what he calls the *establishment astronomy*, he sees in the CBR, and particularly in its long hoped for ripples finally discovered in 1992, the proof that the universe is not expanding [11, pp. 236–238].

As quantitative proof of the dependence of redshift on age rather than on distance, he cites the observation that companion galaxies of the largest galaxy in a group of galaxies have systematically larger redshifts than this dominant central galaxy which they are orbiting and which engendered them [11, pp. 62–64]. In the customary interpretation of the redshift, the distribution of the redshifts of the companions should be approximately evenly distributed about that of the dominant one as some should have an approaching velocity and others a receding one.

In particular, the Andromeda galaxy is the dominant galaxy, the parent galaxy, of the Local Group of which our Milky Way is a member [11, pp. 62, 69]. The companion galaxies are the end point of the evolution of quasars born of the parent galaxy [11, p. 84]. As evidence for the fact that the companion galaxies are the result of ejections from the central galaxy, Arp calls attention to the fact that the satellite galaxies are preferentially along the axis of rotation of the dominant galaxy.

The Magellanic Clouds are also members of the Local Group and would appear to be the Milky Way's younger offspring [11, p. 95]. This statement as well as the preceding one involving the Andromeda galaxy go against conventional wisdom and illustrate the fact that where Arp sees ejections, others may see collisions.

Arp has no taste for, or high opinion of, general relativity and, in particular, for curved space or curved space–time [11, pp. 254–255].

3.2. *"Let There Be Matter"*

Arp's contention, also shared by his friends Hoyle, Burbidge and Narlikar (see below), that matter is continually being 'created' is receiving support from recent experimental results.

"Let there be matter". This phrase, reminiscent of Genesis, is from Jeffrey Winters, (*Discover* magazine, December 1997) who writes:

> But like any equation, $E = mc^2$ works in both directions, at least theoretically. That is, it should be possible to convert energy into matter. Now a team of physicists has accomplished just that: they have transmuted light into matter. 'We're able to turn optical photons into matter', says Princeton physicist Kirk McDonald, co-leader of the team. 'That is quite a technological leap'.
>
> Until now, no one had directly created matter from light. 'Back in 1934 physicists realized that it would be possible to do this in principle' says McDonald, 'but it just wasn't technically feasible'.

The experiment is reported in *Physical Review Letters* (vol. 79, p. 1626). It consists in injecting a beam of very high energy electrons from a linear accelerator into an extremely tightly packed photon beam, slamming some photons backwards into others. The collisions created electrons and their antimatter siblings – positrons.

One may also consult Kirk McDonald's website [133].

Alexander Levichev says that this result is "not a surprise for a mathematician. From the representation theory viewpoint (namely, in its chronometric version) a photon is an electron–positron bond".

3.3. *Confirming Arp's Abnormal Redshifts and Attempts at Explaining them*

3.3.1. *Sympathetic Opinions of HBN and Pecker*

We often use the acronym HBN to designate the three scientists Fred Hoyle, Geoffrey Burbidge and Jayant V. Narlikar to whom we devote a later section.

One of the main arguments held against Arp's conclusion was the discovery of gravitational lensing, which allows us to see several images of a single quasar in the vicinity of a perturbing but much closer galaxy [79, pp. 467, 470].

But Arp denies this [11, pp. 169–171] and HBN also argue lengthily against this possibility beginning on p. 147 of [15]. Pecker shares this opinion; he writes:

> [...] there are gravitational lensing effects, and images of real quasars given by this mechanism. There are, however, other quasars which cannot be accounted for by any effect of that sort. [...] We feel that, at the present time, the evidence for abnormal redshifts, whatever their cause, is truly convincing [79, pp. 470–472].

G. Burbidge and others have conducted broad statistical studies in 1971 and again in 1989 [15, pp. 122–124] which claim to have demonstrated the existence of Arp's associations. Other studies, notably by A. Webster in 1982, concluded otherwise. On the basis of the computer search of 1989 based on the catalogue of all quasars known in 1987 (numbering about 3000), HBN assert "without any possibility of doubt" that the overwhelming majority of the 400 pairs consisting of a quasar and a galaxy separated by less than 10 minutes of arc are physically associated and hence that the quasar in each case is at the same distance as the associated galaxy, requiring the large observed redshift of the quasar to have a dominant intrinsic property.

HBN believe that the effect of anomalous redshifts must be rare for otherwise if it were widespread in galaxies as they apparently are for quasars, there would be a large scatter in the Hubble diagram and no Hubble relation would be found for normal galaxies [15, p. 327].

3.3.2. Emil Wolf's New Optical Redshift Mechanism

An important discovery made in 1986 (see, for instance, [117] and [118]) that its finder calls *correlation-induced spectral changes* might explain Arp's discordant redshifts. It was made by Emil Wolf, professor of optical physics at the University of Rochester, and appears to have been generally ignored or incorrectly explained. Wolf is coauthor with Max Born of the monumental work on optics [13]. According to Wolf's theory, in some well defined circumstances one may "generate shifts of spectral lines which are indistinguishable from those that would be produced by the Doppler effect" [118, p. 48]. These theoretical predictions were subsequently verified by experiments conducted by two of Wolf's colleagues, G.M. Morris and D. Faklis [70,71].

Wolf writes:

> [...] contrary to the usual claims there is a mechanism, rooted in statistical optics, which may give rise to Doppler-like shift of spectral lines, even though the source and the observer may be at rest relative to each other. Whilst this mechanism does not necessarily challenge the Big Bang theory it may resolve a long standing controversy relating to pairs of astronomical objects (e.g. certain galaxies and quasars) which have very different redshifts and yet appear to be connected.

He adds:

> It has also been shown that scattering on a fluctuating medium whose correlation function is strongly anisotropic may generate shifts of spectral lines which are indistinguishable from those that would be produced by the Doppler effect [118, pp. 41, 48].
>
> The shifts may be arbitrarily large [36].
>
> Red shifts as well as blue shifts can be produced by this mechanism, depending on the scattering geometry [35].

In his *Plasma cosmology* article of 1992 [82], Anthony L. Peratt gives an instructive description of the Wolf mechanism:

> A mechanical analogue of Wolf's discovery is a pair of tuning forks with nearly identical resonant frequencies (pitches). If these forks are connected together by, say, a sounding board, the coupling is strong and the resonant frequencies tend to get "dragged down" to lower ones. In other words, the wavelength is lengthened or redshifted. This phenomenon has been verified experimentally with light waves and for sound waves for coupled speakers. [...] This mechanism can be extended from the case of two radiating point sources to that of a whole collection of such objects, for example a plasma cloud. Wolf and his colleagues have shown that such a cloud can produce shifts that closely mimic the Doppler effect.

3.3.3. *Are They Compatible with Chronometric Cosmology?*

In [99, p. 2951], Segal and his co-writers comment on Arp's anomalous redshifts and the quantization of redshifts from the viewpoint of their chronometric cosmology as follows:

> In connection with phenomenological indications for possible discordant redshifts and the quantization of redshifts, it should be noted that the chronometric redshift $z = \tan^2(t/2)$ is a function of the *duration t* of the time interval between the emission of the photons and its absorption in the process of observation. In particular, a photon in a localized *photon trap*, if such exist, would experience the redshift given by this equation while traversing a negligible distance. The effect of temporary trapping of a source at distance r would modify the redshift–distance relation in accordance with the equation $z = \tan^2[(r + \delta t)/2]$, where δt is the time spent in the trap. In chronometric theory, the difference between the global energy of a photon and its locally observable linear component (i.e. its Minkowskian energy) is essentially gravitational, from a general theoretical standpoint, representing an attractive force that scales like the Newtonian potential, etc. The trapping of photons would thus be analogous to the gravitational binding of massive particles, and it would not be surprising if such traps exist in regions of extreme physical conditions (J.A. Wheeler, *Geometrodynamics*, 1962). By virtue of limitation to such regions, the effect on overall quasar statistics would be marginal and hardly detectable until substantially larger complete samples had been observed; but on occasion, discordant redshifts of the type proposed by Arp would be expected to result.

In a 1992 preprint of a paper that was to appear the next year under the title of "The redshift–distance relation", with the following passage deleted, Segal expresses his view about Arp's anomalous redshifts and the quantization of redshifts thus:

> The existence of discordant redshifts of the type proposed by Arp is subject to objective statistical test by their expected impact on the distribution of dispersion in apparent magnitude in large complete samples. They should appear as an underestimate of this dispersion when this is predicted in random samples by CC. The quantization of redshifts proposed e.g. by Burbidge could result from interfaces between particle and antiparticle regions in CC (in which particle–antiparticle symmetry is a priori natural), and could be similarly tested directly by analyses of observed V/V_m (a spatial uniformity test described in [102, pp. 163, 164]) distributions in complete samples.

4. Challenging the Cosmological Principle: Finite Topological Spaces with Holes

4.1. *Mirror Images in the Night Sky?*

A small group of astrophysicists and mathematicians has emerged who, while supporting most of BBC, deny the cosmological principle and propose unanticipated shapes for the space we live in. More specifically, the cosmological principle is demoted from the global geometry to the local geometry. Mathematically, local homogeneity means that for any two points of space there exists neighbourhoods that are isometric; while local isotropy means that for any two directions from a point of space, there exists an isometry of some neighbourhood of that point onto itself which leaves that point fixed (i.e. a local isometry) and maps one direction on the other [115, pp. 96, 264, 265; 31, p. 136; 119, p. 381].

This dissent opens the door to the possibility of space being finite irrespective of the density of matter in the universe though this density, as in standard BBC, still determines the constant curvature of space and thereby, presumably, the fate of the universe. Perhaps more spectacularly, this downgrading of the Copernican principle also suggests the possibility that space may be multiply-connected, i.e. not simply connected, the way a doughnut surface is and hence that light originating from far away may reach us via several paths thereby generating several images of the same object, including of our own galaxy, at different epochs.

Just as it is with the three-sphere as a model of space which goes back at least to the mathematician Riemann in 1854, this idea of a multiply-connected universe is not new, since as early as 1890, the mathematician Felix Klein imagined that space might be a 3-torus which is a flat three-dimensional analogue of a doughnut surface (which is not flat). The astrophysicist Karl Schwarzschild [89] briefly mentioned this idea in 1900 [115, p. 280]. The idea that the homogeneity of space might be illusory with the above mentioned consequential hypotheses as to the shape of space and the multiplicity of images of a single object was later pursued, for instance in a 1986 paper [24] by G.F.R. Ellis and G. Schreiber.

A subgroup of this school of thought, now making the headlines [52,25,114] appears convinced that the density of matter-energy marginally favors a positively curved space model, and has found reasons in the analysis of anisotropies in the CBR to announce that the space we live in has the unexpected shape of a small dodecahedron whose pairs of opposite faces are somehow identified and which is known as Poincaré space.

Janna Levin ends the first chapter of her book [51], *How the Universe Got Its Spots: Diary of a Finite Time in a Finite Space*, with a plea for understanding:

> I'll try to tell you my reasons for believing the universe is finite, unpopular as they are in some scientific crowds, and why a few of us find ourselves at odds with the rest of our colleagues.

Others [1] think that the geometry is Euclidean i.e. the curvature is zero and from known geometrical results they can list all such possibilities. There are ten such, of which four are infinite. The simplest of the remaining six is the flat 3-torus obtainable from a cube by identifying or, one says, by abstractly gluing, the opposite faces of all three pairs of parallel faces. A two-dimensional analogue is the flat 2-torus obtainable from a square by identification of its parallel edges. This is topologically the same object as the doughnut-surface torus but geometrically the two must be distinguished as the first is flat and the second is curved. The (topological) 2-torus is a surface with one hole. Of course three-dimensional manifolds are harder to visualize.[8]

The flat 3-torus may be compared to a room all six faces of which would be mirrors. This exemplifies the possibility of a large number of images of a celestial object being visible should space result from the identification of some points at the edge of a fundamental domain such as a cube in the case of the flat 3-torus.

[8] The recommended book by Jeffrey R. Weeks *The Shape of Space* [115] and the article by William P. Thurston *How to see 3-manifolds* [106] will be found quite helpful in that respect. One may also read Chapters V and VIII in the excellent book by Richard Osserman *Poetry of the Universe* [78].

Mathematically speaking, such a “small universe”, i.e. a typical such compact model of space, is obtainable from the spatial part of any FLRW space–time by suitable identifications under a discrete group of isometries. The original space can be recovered from the small universe as its universal covering space which is simply connected. An observer in the small universe “sees” the universal covering space – his observations will be exactly the same as those of an observer in the covering space with an exactly repeating set of galaxies [24, pp. 98, 99]. This would be the root of the illusion of space being homogeneous.

As experimental corroboration of these ideas, two methods are being used. They have tantalizing names: the *cosmic crystallographic method* and the *circles-in-the-sky method.*

Cosmic crystallography looks at the 3-dimensional observed distribution of high redshift sources (e.g. galaxy clusters, quasars) using catalogues of cosmic objects in order to discover repeating patterns in their distribution, much like the repeating patterns of atoms observed in crystals. This seems to be independent of BBC and could perhaps also be used in the context of chronometric cosmology. This method appears to have yielded few results [43; 115, Sect. 21].

The second method appears to be more promising and it is on its basis that the fantastic dodecahedron announcement was made in October 2003. It relies on an analysis of the irregularities in the Cosmic Background Radiation thought of as an echo of the Big Bang. The temperature fluctuations of the CMB may be decomposed into a sum of spherical harmonics, much like the sound produced by a musical instrument may be decomposed into ordinary harmonics. It is on the basis of an analysis of the CMB temperature fluctuations as measured by the satellite WMAP that the Poincaré space has been selected as a model for our physical space [52].

Poincaré space may be represented by a dodecahedron (a regular polyhedron with 12 pentagonal faces) whose opposite faces are glued after a 36 degree clockwise twist; such a space is positively curved, and is a multiply connected variant of the hypersphere, with a volume 120 times smaller [115, Sect. 16].[9]

Of course, all this rests essentially on some BBC hypotheses and the reliability of these conclusions cannot exceed that of these assumptions! At the time of writing considerable uncertainty still surrounds this analysis of the observed CMB temperature fluctuations [114, pp. 617–618]. WMAP data find that certain features of CMB harmonics align with the ecliptic plane, the plane of the earth’s orbit, at 99.9% confidence level, calling into question the presumed cosmic origins of these features and suggesting instead some hitherto unknown solar system contributions to the CMB. It is appropriate here to quote the following excerpt from a letter of I.E. Segal published in *The New York Times* of May 13, 1992 shortly after the discovery of the CMB fluctuations which were desperately hoped for to help take BBC from the hook:

> The marginally observable fluctuations in the cosmic background radiation are likely to be confirmed if only because such fluctuations would be a concomitant of almost any known type of possible physical origin for this radiation. They are not at all uniquely indicative of a Big Bang.

[9] One can download free of charge, interactive 3D software to explore this space and other 3-manifolds from Weeks’ Topology and Geometry software website [137].

5. The Steady-State Cosmology Resurrected: The Quasi-Steady-State Cosmology of Three Venerable Maverick Stalwarts

5.1. Teachings of the QSSC

Here comes, from three continents, a resolute triumvirate comprising the most well-known dissenters from the conventional wisdom, i.e. BBC: Fred Hoyle, Geoffrey Burbidge and Jayant V. Narlikar.

Sir Fred Hoyle, who died on August 20, 2001, was professor of astronomy at the University of Cambridge, Geoffrey Burbidge is professor of physics at the University of California at San Diego, and Jayant V. Narlikar is at the Inter-University Center for Astronomy and Astrophysics in Pune, India.

The original steady-state cosmological model was developed in 1948 by Bondi and Gold, and Hoyle. This model was based on two interrelated postulates. First, the *perfect cosmological principle* according to which the universe has always and will always look the same to any observer. Second, there is no such thing as a Big Bang and matter is created, emerging spontaneously out of nowhere, at a uniform rate determined by the expansion, rather than being created at time $t = 0$ as in BBC [38, p. 142].

Apparently definitely defeated by BBC in the 1960s, the original steady state cosmology has made a comeback in the 1990s under the name of *quasi-steady state cosmology* (QSSC) under active development since 1993 by its initiators.

The geometry of QSSC is a Friedmann–Lemaître–Robertson–Walker space–time in which the time-dependent scalar factor $R(t)$ is the product of a periodic sinusoidal pulsation function and a slow exponential. This gives rise to a bouncing universe whose *radius* $R(t)$ (no finiteness of space intended by the use of the word *radius* which is a common name for $R(t)$) oscillates between a maximum size and a *nonzero* minimum size, with these extremes and the amplitude slowly increasing with time but with a fixed frequency.[10]

Near an oscillatory maximum, the universe is sufficiently diffuse that light propagation is essentially free. This, together with the long time scale of a maximum phase and the large-scale homogeneity and isotropy in the distribution of galaxies, causes the radiation to also acquire a high degree of homogeneity that persists through subsequent cycles. Thus an explanation of the remarkable uniformity of the CBR is obtained [14, p. 41].

A scalar field analogous to the one that appears in inflationary models of BBC permits new matter to appear in an already existing universe [14, p. 39].

While BBC hypothesises that a typical galaxy centre is occupied by a massive black hole surrounded by an accretion disk which emits only gravitational energy, QSSC teaches that galactic nuclei are near-black holes in which mass and energy are created. The authors assert, as Arp does, that there is overwhelming evidence of quasar ejection from active galactic nuclei. Some quasars, in their view, are quite nearby.

They regard the observed phenomenon of the ejection of condensed objects from excited galaxy nuclei as *prima facie* evidence for galaxy formation [14, p. 43].

The authors reject several assertions of BBC for which they think there is no *primary* observational evidence.

[10] The graph of the scale factor is illustrated in [16, p. 732].

Although they concede the existence of some baryonic dark (i.e. nonluminous) matter in galaxies on the basis of the flat rotation curves of spiral galaxies they contend that some clusters of galaxies are not gravitationally bound and that their masses are exaggerated as conventionally computed. They argue that the gravitational merger hypothesis is overemphasised and that the innumerable observational evidences in favour of ejections and explosions of galaxies are almost disregarded [14, pp. 38, 42, 44].

On the basis of our understanding of stellar evolution leading to the conclusion that in general matter will only be tied up in luminous stars for a comparatively small part of its life, they assert that there is every reason to believe that a significant fraction of all the matter in the universe is dark, much of it as diffuse gas ejected at the end of stars' lives and the rest made of dead stellar remnants, namely, slowly cooling white dwarfs, neutron stars and near-black holes [15, p. 281].

They deny the existence of nonbaryonic dark matter invoked for large-scale structure scenarios, or to attain the closure density. They talk of "continuing failure of attempts to identify this nonbaryonic dark matter [14, p. 38].

Contrary to Big Bang cosmology which requires that all the matter in the observable universe be created in one single moment occurring 10^{-36} second after the Big Bang itself, they relate matter creation to conditions within near-black holes. It is a process that takes place in many locations [15, p. 107]. The products of creation expand in a "universal sea" in BBC but in "separated fireballs" in QSSC [15, p. 109].

The light elements, like all other isotopes in the periodic table, are of an astrophysical origin, i.e. are produced by astrophysical processes. This again is contrary to the prevailing idea that the light elements were formed almost entirely at the time of the Big Bang [15, p. 107].

In 1957, it had already been shown that of the 320 isotopes of the chemical elements all but eight were synthesised by nuclear processes in stellar interiors. This short inventory of problematic elements consisted of light nuclei and HBN claim that, of this list, deuterium is the last survivor which still poses a difficulty, i.e. the only one for which primordial nucleosynthesis might be needed. Yet they also conclude that this last case is uncertain and that it would seem that any nucleus heavier than the proton has been synthesised by processes associated with stars [14, p. 41].

The CBR can be explained by the hypothesis that all helium-4 is synthesised from hydrogen in stars as opposed to Big Bang nucleosynthesis. This alone defeats two major claims justifying BBC [14, p. 38].

Although helium is known to be produced from hydrogen inside stars, BBC argues that stellar synthesis can account for only a negligible contribution to the observed abundance of helium because of lack of time since the Big Bang for such slow astrophysical processes to have produced most of the observed helium. Most of the production is explained in BBC by primordial synthesis in the early universe [15, p. 96].

Observations over many years have accumulated good statistical evidence that many high-redshift quasars are physically associated with galaxies having much smaller redshifts, sometimes with a luminous bridge connecting these objects. This suggests, in agreement with Arp's interpretation, that a quasar ejected from a low-redshift parent galaxy possesses an intrinsic redshift component not associated with any recessional motion [14, p. 43; 15, p. 122].

HBN's theory of the observed redshift z_0 recognises that it has three components: one due to the cosmological expansion denoted z_c, a Doppler component due to the motion of the object in question denoted z_d, and finally one of intrinsic origin denoted z_i. They relate them with the following formula: $(1 + z_0) = (1 + z_c)(1 + z_d)(1 + z_i)$. From an analysis of this formula they conclude [15, p. 332] that the quasars from a population which show sharp peaks in its redshift distribution (the phenomenon of redshift quantization) must be comparatively local objects: "The peaks are most prominent in quasars which can be clearly associated with nearby galaxies with very small values of z_c."

One prediction the QSSC which could be tested with future very large telescopes is that galaxies belonging to a preceding cycle are indeed blue shifted [79, p. 501].

HBN introduce a creation function. The properties of homogeneity and isotropy for the whole universe for their creation function are rejected as this would in their view require that the curvature k be 0. The cases $k = +1$ and $k = -1$ arise in regions of the universe as consequences of inhomogeneities in the creation rate. A high local creation rate leads to $k = +1$ and to a bouncing region of the universe i.e. one in which phases of expansion and contraction alternate, matter creation episodes taking place at the oscillatory minima each producing some increase in the scale of the maxima. A low local creation rate gives rise to an ever-expanding region of the universe, a *growing hole*. They regard the entire observable universe as a $k = +1$ region into the surrounding universe to which their Friedmann–Robertson–Walker metric does not strictly apply. They speak of the observable universe as being a *near-black hole* as seen from outside. Within it there are regions of condensation and also expanding holes, but never strictly formed in a topological sense [15, pp. 194–196]. We are further referred to [76].

HBN have much in common with their friend Arp, coauthoring some papers. One point that keeps them apart is Arp's contention that there is no expansion of the universe while HBN claim that the matter creation episodes are causing it to expand. Arp says that if HBN accepted that matter be created with *zero* mass instead of having the particles produced with terrestrial masses, they would do away with the need for an unstable expansion i.e. their bouncing universe [11, p. 238].

6. The Eternal Self-Sustaining Plasma Universe: Hannes O.G. Alfvén Rehabilitates Electromagnetism

6.1. A Major Role for Electromagnetism

Electromagnetism is the main character in the plasma universe scenario. General relativity is downplayed but special relativity is maintained [3, p. 597]. Plasma cosmology holds that 99.999% of the volume of the universe is made up not of "invisible matter", but rather of matter in the plasma state. Electrodynamic forces in electric plasmas far exceed the gravitational force and therefore are the main actors that shape the cosmos all the way to superclusters of galaxies. Gravity is the only force that conventional cosmology based on general relativity takes into account with its metric tensor coupled with fluid dynamics. The *fluid of galaxies* idealisation defined by the two hydrodynamical parameters *density* and *pressure* ignores electromagnetism, as we have noted earlier.

The proponents of this theory assert that the universe is incomprehensible without taking into account the huge electrical currents and magnetic fields that permeate it and whose existence is denied or ignored by mainstream cosmology. Hannes Alfvén[11], an electrical power engineer and a Swedish Nobel laureate, has founded modern plasma physics, i.e. the physics of electrically conducting gases, which he has been studying since the 1930s, and has coined the phrase '*plasma universe*' to describe the view of the universe he espouses. Eric Lerner from Lawrenceville Plasma Physics in New Jersey, has championed and popularised this idea in [46].

The electromagnetic force has a far greater range than the gravitational one since the former varies as the inverse of the distance whereas the latter varies as the inverse of the *square* of that distance.

"In this theory, a galaxy, spinning in the magnetic field of intergalactic space, generates electricity, as any conductor does when it moves in a magnetic field" [46, p. 46].

Past and future eternity are postulated for the plasma universe. The shape of space is not emphasized: space is assumed to be infinite but we think the theory could accommodate a finite space as well [46, p. 388 and its footnote; and also p. 279].

6.2. What is a Plasma?

Anthony L. Peratt from the Los Alamos National Laboratory, defines 'plasma' as follows in his book *Physics of the Plasma Universe* [81, p. 1]:

> Plasma consists of electrically charged particles that respond collectively to electromagnetic forces. The charged particles are usually clouds or beams of electrons or ions, or a mixtures of electrons or ions, but also can be charged grains or dust particles. Plasma is also created when a gas is brought to a temperature that is comparable to or higher than that in the interior of stars.
>
> Plasma is a fourth state of matter, different from a solid, liquid or gas, but most closely resembling the last [...] Because of its free electrons, a plasma is a good conductor of electricity, much better than copper, silver or gold. Lightning offers one of the most dramatic manifestations of this property [82, p. 136].

If, as it is claimed, 'plasma makes up more than 99 percent of the visible universe', it is clear that understanding the dynamics of plasma is a key to a better comprehension of the universe.

Stars, for example, are gravitationally bound plasmas, while all of interstellar and intergalactic space is plasma.

Whenever plasmas exist, they produce prodigious amounts of electromagnetic radiation.

6.3. Observational Support for the "Plasma Universe"

Plasma electric currents were first imagined by the Norwegian scientist Kristian Birkeland (1867–1949) [34] in his attempt to understand the aurora borealis. Although supported both by his own observations and by his experiments in the laboratory, where he was able to simulate the aurora, Birkeland's theories failed to gain widespread acceptance until essentially confirmed by satellite evidence in the 1970s.

Modern plasma cosmologists have been heavily influenced by Birkeland's earlier research. In 1950, Hannes Alfvén, who later won a Nobel Prize in physics for his so-

[11] Hannes Alfvén died in April 1995; he worked at the Royal Institute of Technology, Stockholm and the University of California, San Diego.

lar studies, proposed that streams of electrons move at nearly the speed of light along magnetic-field lines not only in the Earth's magnetosphere and above the Sun, but also throughout the cosmos. If so, sheets and ropes of electric current should criss-cross the universe in ever-increasing sizes. These currents, Alfvén thought, should give the universe a cellular and filamentary structure.

Astronomers accepted Alfvén's notion of widespread synchrotron radiation but refused to believe that electric currents give rise to the large-scale structure of the universe.

However, the filamentary structure of the distribution of galaxies is confirmed by the three-dimensional maps of Tully and Fischer which show that nearly all the two thousand galaxies in their *Atlas of nearby galaxies* [109] are concentrated into an interconnecting network of a few large filaments called superclusters [46, p. 21].[12]

Peratt's book [81] is a presentation of the mathematical laws of physics that govern the behaviour of plasmas. It provides the fundamental argument for why electrical effects cannot be ignored in any modern study of the cosmos.

Peratt uses a large computer to apply Maxwell equations governing the forces produced by, and the interactions between, electric and magnetic fields to each of a huge ensemble of charged particles. He calls this *Particle in Cell* (PIC) simulations. His results are almost indistinguishable from astroimages of actual galaxies.

Some simulations concern the behaviour of two interacting Birkeland plasma electric currents. The computer images so obtained bear striking resemblance to real ones depicting the full range of galaxy types. It is very important to note that electromagnetic processes rather than gravitational ones create these images. As already pointed out, the electromagnetic force between the two currents, which falls off in direct proportion to the distance between them, is therefore much stronger than the gravitational force which falls off as the square of the distance. Just compare Newton's law of universal attraction to Ampère's law giving the strength of the magnetic field created by an electrical current in a straight wire.[13]

Computer simulations to understand the cosmos through plasma physic are still being conducted on some of the most powerful machines in existence at the Los Alamos National Laboratory [130].

6.4. The CBR, Nucleosynthesis and the Redshift in the Plasma Universe

Eric J. Lerner has developed a Plasma theory of nucleosynthesis and of the CBR. In a soon to be published (but already web accessible [140]) review article [48] he expounds and updates them, and also compares them quite favourably to the ones of BBC.

Alfvén [4, p. 9] and Lerner [46, pp. 52, 278–280, 425–430] express doubts about the nature of the redshift. They speculate that matter/antimatter collisions created an explosion or a big bang in one part of the universe thus creating the Hubble expansion in that small corner of the infinite universe that we can observe: "But this was in no way a Big Bang that created matter, space and time."

Thus there is perhaps no general expansion, only local occasional ones in an eternal universe. Apart from the conjectured infinity of space, this looks much like what Segal

[12] A color illustration of this is visible on a page of [132]: "http://home.pacbell.net/skeptica/structure.html". On Brent Tully's website [139] at the Institute for Astronomy of the University of Hawaii, one can find a '*Flight through the Local Supercluster*' amongst other interesting software. Tully supports BBC.

[13] Cf. Richard P. Feynman's *Lectures on Physics* (1964), Vol. II, pp. 13–5.

says in the context of CC. An alleged weakness of the Einstein Universe is that it would be unstable from the point of view of general relativistic hydrodynamics. As already noted, Segal considers this argument naïve. In that connection it is worth noting that Gerald S. Hawkins of the Harvard-Smithsonian Observatories writes in [32, p. 197]: "Hannes Alfvén and his colleagues have shown that a nonexpanding universe can be stabilized by electric and magnetic forces."

Edward L. Wright offers criticism of the Plasma Universe on his website [123] as he does of most cosmologies other than BBC.

7. The New-Tired Light Theory of the Redshift: The Nonexpanding Universe of Paul Marmet

7.1. Old Tired-Light Theories

Tired-light theories attempt to account for the cosmological redshift with variants of the hypothesis that the photons lose energy on their long journey to us generally through encounters with known or hypothetical particles or fields, or else, atoms or molecules.

A tired-light mechanism based on a photon-photon interaction was proposed in the 1950s by E. Findlay-Freundlich and Max Born. Later, Jean-Claude Pecker and Jean-Pierre Vigier with several co-authors could explain many facts on the basis of an interaction between photons of nonzero mass with a hypothetical particle [79, pp. 510–511].

7.2. Paul Marmet's New Tired-Light Theory

Paul Marmet is a Canadian physicist. He distinguishes himself from all other scientists we have mentioned so far by his rejection, not only of general relativity [63] but also of special relativity, as expounded in his books [61,65] and in several papers most of which are available on his website [126], sometimes in updated versions.

In his 1988 paper [60], he introduced his *New Non-Doppler Redshift* based on inelastic photon–molecule collisions. This leads to a new tired-light mechanism for the cosmic redshift which he developed further the next year with Grote Reber in [66], where the authors explain that:

> In this model the redshift is produced by inelastic collisions of photons on atoms and molecules. Some scientists reject this mechanism because they are not aware that most photon–molecule collisions do not lead to any significant angular dispersion of photons in all directions.

The 1999 discovery by Valentijn and van der Werf [110] of large amounts of relatively *warm* hard to detect *molecular* hydrogen in a galaxy, which Marmet and Reber had foreseen in [66] and [62], leads Marmet to forecast the detection of large amounts of (*colder* and hence still harder to spot) *molecular* hydrogen throughout space. It is with these molecules, he thinks [64], that photons collide inelastically and with little scattering on their long journey from galaxies to the earth.

This 1999 finding of *molecular* hydrogen seems to resolve the problem of the constancy of tangential velocities of matter in galaxies according to the discoverers and also according to what Marmet and Reber had conjectured in the above papers. Valentijn declares:

> Our results give a much stronger footing for the 'ordinary matter' simple solution of the dark matter problem, in the form of massive clouds in the disks of galaxies.

However, Marmet argues that this discovery of *molecular* hydrogen has other significant corollaries. To support his new tired-light mechanism he writes in [64]:

> The recent discovery of an enormous quantity of *molecular* hydrogen not only solves the problem of missing mass; it also solves the problem of the redshift, in a non-expanding unlimited universe [...]. We know that light interacts with a transparent medium, because its velocity is reduced, without scattering, as calculated and observed using the simple index of refraction of gases. Cosmic light, moving across billion of light years, suffers an almost unimaginable number of collisions with those transparent molecules of hydrogen in the universe.

Marmet continues:

> [...] as a result of the large amount of *atomic* hydrogen already observed in space, and the extreme stability of *molecular* hydrogen, the chemical equilibrium giving the relative abundance between *atomic* hydrogen and *molecular* hydrogen in space, strongly favors the formation of the diatomic form (H_2) over the monoatomic form. We must thus conclude that the recent discovery of H_2 is no surprise, and should have been expected from the known facts concerning the natural equilibrium between H_2 and H. It is expected that much more colder H_2 will also be discovered.

Marmet arrives at the Hubble law in a nonexpanding universe:

> Because *atomic* and *molecular* hydrogen have an approximately homogenous distribution in the universe, this induces a non-Doppler redshift, which is proportional to the distance of the light source.

7.3. Discordant Judgments

However, discordant voices are heard, even from non-conventional cosmologists, about Marmet's redshift mechanism. In *The Big Bang Never Happened*, Lerner contends (pp. 428–429) that there cannot be as much intergalactic matter as Marmet claims there must be to justify his redshift theory, for otherwise "Such a high matter density would have enormous gravitational effects that simply aren't observed." For his part, Arp rejects all tired-light explanations of the redshift since he rejects the notion that the redshift be a distance indicator. In addition, he calls attention to the fact that within our own galaxy:

> as we look to lower galactic latitudes, we see objects through an increasing density of gas and dust until they are almost totally obscured and no increase of redshift has ever been demonstrated for objects seen through this increased amount of material [11, p. 97].

8. Mordehai Milgrom's Modified Newtonian Dynamics: The Embryo of a New Cosmology Without Any Dark Matter

The *dark matter problem*, also known as the *missing mass problem*, apparently partly resolved by the 1999 discovery of *molecular* hydrogen in galaxies and which arose in the early 1980's by the observation of the *flat rotation curve*s in spiral galaxies is also offered another solution, this one put forward in 1983 by Mordehai Milgrom from the Weizmann Institute in Rehovot, Israel. It is known by its acronym MOND which stands for *Modified Newtonian Dynamics* or sometimes for *Modified Nonrelativistic Dynamics.* In [68], Milgrom attempts to lay the foundations of *a MOND-inspired cosmology, which, at any event, would start with no dark matter.*

The *dark matter problem* may be summed up thus. If the mass of a galaxy were concentrated near its center from which its luminosity falls off rapidly with distance, the stars in the galaxy at increasing distances from the center would have decreasing tangential orbital velocities. Contrary to that expectation it was found that this velocity is essentially independent of distance. One possible conclusion, which appears to be corroborated by the molecular hydrogen discovery, is that the light distribution in a galaxy is not at all a guide to the mass distribution [88,87].

Instead of looking for this missing mass MOND attempts to resolve the problem by challenging Newton's second law of motion usually written as $F = ma$; F being any force, m the mass acted upon by F and a the resulting acceleration. Although this law is well established in laboratories and in the solar system, it is argued that it may no longer be valid when small accelerations, such as the ones found at larger distances in galaxies, are involved.

MOND introduces a constant a_0 which has the dimensions of an acceleration and replaces $F = ma$ by $F = ma^2/a_0$ but only when $a \ll a_0$. As a consequence one obtains a modified universal attraction law which yields larger accelerations when the Newtonian acceleration is much smaller than a_0:

> The basic point of MOND, from which follow most of the main predictions, can be simply put as follows: a test particle at a distance r from a large mass M is subject to the acceleration a given by $a^2/a_0 = MGr^{-2}$ when $a \ll a_0$, instead of the standard expression $a = MGr^{-2}$, which holds when $a \gg a_0$.

The theory is basically nonrelativistic. Milgrom writes on his website [128]:

> Several relativistic theories incorporating the MOND principle have been discussed in the literature, but none is wholly satisfactory.

The theory has its supporters: for instance Tom van Flandern [111] writes:

> Milgrom's model (the alternative to "dark matter") provides a one-parameter explanation that works at all scales and requires no "dark matter" to exist at any scale.

HBN, on the other hand, are not enthusiastic [15, p. 286]:

> Milgrom's proposal [...] is an *ad hoc* modification of Newton's law designed to suit the particular phenomenon under consideration.

9. Epilogue

9.1. Sound Science, Beliefs and Fantasies

Cosmology is in imminent danger of deserting the ground of sound science for the terrain of beliefs and fantasies. It is shameful that in most accounts of contemporary cosmology all options other than BBC are mentioned, if ever, only to be dismissed without discussion. It is appropriate here to remind some basic canons of rational knowledge as opposed to articles of faith of an established orthodoxy. Too many cosmologists have forgotten Occam's razor, the epistemological principle which normally underlies all scientific theory building: one should not make more assumptions than the minimum needed. Also at stake is disrespect for disquieting observed facts and their observers: the case of Arp's abnormal redshifts and its discoverer's forced early retirement come to mind. On the other hand pure speculations are routinely presented as facts: *exotic nonbaryonic dark matter* and *dark energy* make up most of the universe!

There is an urgent need for more open-mindedness; for readiness to abandon long held views in the face of contrary observational evidence; for willingness to revise fundamental assumptions; for no sweeping of facts under the carpet; and for a free flow of information. Attempts at preventing publication of views contrary to the conventional wisdom are absolutely scandalous: astronomers of the *USA National Academy of Science* doing their best to prevent Segal from publishing in the *Proceedings of the NAS*; Alfvén's papers and those of other plasma physicists routinely rejected by astrophysical journals for being in contradiction with common thinking. Documented objections to widespread beliefs must be met and not brushed aside or ignored: even opposition to special relativity deserves a response.

9.2. Apology of Chronometric Cosmology

My view is that Irving Ezra Segal is the true continuator of Einstein's genius in cosmology. All adepts of the universal expansion hypothesis would be well advised to look carefully at Segal's chronometric cosmology. Its redshift–distance relation has met the test of all available reliable data whereas the Hubble law does not hold water. CC faces none of the tribulations afflicting BBC.

9.3. Will Big Bang Cosmology Ever Fall?

Unless BBC somehow resolves the enormous difficulties it faces, it should rationally be forsaken but, in view of its present social status and a subservient popular press, it would take more than a small flock of missionaries to have any of the other contending theories (or a coalition thereof) also facing their own problems, replace it. Mainstream science may remain on the wrong track for a long time for reasons that have little to do with rationality. Meanwhile this will not divert all valiant minds, amongst them many believers in BBC, from the pursuit of truth.

In the meantime a downturn in their arrogant tone, that borders on fanaticism, would be a welcome change in the discourse of many advocates of BBC [6].

Acknowledgments

I am most thankful, in the first place, to Marco Mamone Capria who is doing a superb job as editor of this volume. His very careful readings and many thoughtful suggestions have been very useful to me. I also owe many thanks to Danièle Dubé, Alexander Mittelmann,[14] Alexander Levichev and Arturo Sangalli for their corrections and ideas from reading earlier versions of this chapter.

[14] "Cold Creation", www.coldcreation.com.

Appendix. The *Minkowskian-Cosmic Times Formula of CC*

For the benefit of the more mathematically minded reader we present here an outline of a proof of Eq. (1) i.e. the *Minkowskian-cosmic times formula of CC* mostly based on [92]. For simplicity's sake we assume, at first, the three-sphere radius r to be unity. As we also assume the speed of light c to be 1, the distance travelled on the three-sphere is equal to the cosmic time elapsed. The formula to be established then becomes simply $x_0 = 2\tan(s/2)$ in which s is cosmic time and $x_0(s)$ is the corresponding Minkowskian time. Two main characters in this drama are Minkowski space–time M and the unit three-sphere S^3. Their roles will be played respectively by $H(2)$, the set of 2×2 complex Hermitian matrices and $SU(2)$, the special unitary group made up of the 2×2 unitary matrices of determinant 1 as we now explain.

Minkowski space M is mapped biuniquely onto $H(2)$ by sending $x = (x_0, x_1, x_2, x_3)$ onto the matrix

$$A = \begin{pmatrix} x_0 + x_3 & x_1 + ix_2 \\ x_1 - ix_2 & x_0 - x_3 \end{pmatrix}. \tag{3}$$

This is an isomorphism between two real vector spaces. The closed future light-cone at the origin O of M including light rays is the set of points

$$\left\{(x_0, x_1, x_2, x_3) \mid x_0^2 - x_1^2 - x_2^2 - x_3^2 \geq 0; x_0 \geq 0\right\}. \tag{4}$$

This light-cone defines the causal structure on M, the light-cones at other points of M being obtained by translations. The above isomorphism maps this light-cone on the set of positive definite Hermitian matrices. Taking this as the light-cone at the origin turns $H(2)$ into a causal manifold isomorphic to M. The real vector space $H(2)$, more exactly, the real vector space $iH(2)$ of antihermitian matrices, to which the causal structure on $H(2)$ can be transferred by the obvious real isomorphism, is the Lie algebra of the unitary group $U(2)$, the multiplicative group of 2×2 unitary matrices. This Lie algebra can be thought of as the tangent space at the unit element of the Lie group $U(2)$. This group acquires a causal structure by translating the light-cone at the identity element of $U(2)$. It matters not whether one uses right or left translations in $U(2)$.

The unit three-sphere S^3 can be identified with the special unitary group $SU(2)$ by virtue of the fact that the generic element of that group is the matrix

$$U = \begin{pmatrix} a + ib & c + id \\ -c + id & a - ib \end{pmatrix} \tag{5}$$

where, the determinant being 1, we must have

$$a^2 + b^2 + c^2 + d^2 = 1 \tag{6}$$

which is the equation of the unit sphere in a Euclidean four-dimensional space.

The point $p = (a, b, c, d)$ of S^3, the unit sphere at the origin in a four dimensional space, corresponds to the above matrix U in this identification. The group $SU(2)$, inherits through this identification, the Riemannian metric denoted ds^2 on the unit sphere induced by the surrounding four space. The group of symmetries of S^3 gives rise to a group of inner automorphisms of the group $SU(2)$ which preserve this metric. This metric is the only one on this group which is invariant under right and left translations.

Another main character in the plot is the Einstein universe $E = R^1 \times S^3$ which, by definition, is endowed with the Lorentzian metric $dt^2 - ds^2$ where dt^2 is the ordinary metric on the real time line R^1 and ds^2 is as above. Its role is played by the product of the additive group R^1 and the multiplicative group $SU(2)$. This group $R^1 \times SU(2)$ is the universal covering group of $U(2)$. The projection map sends an element (s, V) onto the unitary matrix $e^{is}V$. In view of the fact that $e^{is}V = e^{(is+\pi)}(-V)$ this projection factors through the two sheet cover $S^1 \times SU(2)$ where S^1 is the unit circle, i.e. the multiplicative group of complex numbers of module 1.

Now thinking of $M = H(2)$ as the tangent real linear space at the identity of the group $U(2)$, the 0 matrix as a point of $H(2)$ coinciding with the identity matrix I as a point of the Riemannian manifold $U(2)$ we define a causal embedding of $H(2)$ into $U(2)$ using the *Cayley transform* which is a generalisation of the inverse of the stereographic projection. This maps a Hermitian matrix A in $H(2)$ onto the unitary matrix U defined as

$$U = \left(I + \frac{iA}{2}\right)\left(I - \frac{iA}{2}\right)^{-1}. \tag{7}$$

The reverse mapping which generalises the stereographic projection is defined for all U in $U(2)$ except when $U + I$ has determinant 0, by the equation

$$A = -2i(U - I)(U + I)^{-1}. \tag{8}$$

We still need lifting the group $U(2)$ to a section of its universal cover $R^1 \times SU(2)$ as to complete the causal imbedding of Minkowski space M in the Einstein universe E by the sequence of causal mappings

$$M \to H(2) \to U(2) \to R^1 \times SU(2) \to R^1 \times S^3. \tag{9}$$

This continuous map sends an element $U = e^{it}V$ of $U(2)$ where $-\pi < t < \pi$ and V is in $SU(2)$ onto (t, V) in such a way that the identity matrix I is sent to $(0, I)$. Although each element U of $U(2)$ can be written in this form in two ways by virtue of the equation $e^{is}V = e^{i(s+\pi)}(-V)$ the requirement of continuity eliminates the ambiguity in the definition of the map.

In what follows we identify M with $H(2)$ and E with $R^1 \times SU(2)$ keeping in mind the above four steps imbedding of M into E. Hence each point in M has four names: one x in M proper, an Hermitian matrix A given by (5), a unitary matrix U given by (9) and (t, V) as a member of E where

$$U = e^{it}V \tag{10}$$

as above. The stage is now set for the proof of the two-times formula.

One must think of a photon being emitted somewhere on the three sphere and being observed later elsewhere after some cosmic time s. It is important to distinguish between three events all of which belonging to the image of M in E as we suppose that the photon is observed after less than one half-tour of the three sphere merry-go-round which it is circling along a grand circle. The three events are: the emission (t, W) of the photon at cosmic time t at the point W of space $SU(2)$; the observation $(t + s, V)$ of the photon. s cosmic time later at the point V of $SU(2)$; and the event (t, V) when a patient observer starts waiting at V for the arrival of the photon at the moment it is emitted.

Let A be the Hermitian matrix corresponding to the event (t, V) with $t = x_0$ and U be its Cayley transform defined by (7). Let $A(s)$ be the Hermitian matrix corresponding to the event $(t + s, V)$. One obtains

$$A(s) = -2i\big(e^{is}U - I\big)\big(e^{is}U + I\big)^{-1}, \tag{11}$$

where U is defined by (12). This follows from the fact that the Einsteinian temporal translation T_s, the isometry of E which maps any (t, V) onto $(t+s, V)$, once interpreted in the notation of $U(2)$, maps any U onto $U(s) = e^{is}U$. From this one obtains after some calculations

$$A(s) = 2(2aI + bA)(2bI - aA)^{-1}, \tag{12}$$

where $a = \sin(s/2)$ and $b = \cos(s/2)$.

We may safely assume that the observation takes place at the origin of M, and that the cosmic time of emission is $t = 0$ so that $A = 0$, $U = I = V$. It then follows immediately from (12) that

$$A(s) = 2\tan\left(\frac{s}{2}\right)I. \tag{13}$$

By definition the matrix $A(s)$ can be written

$$A(s) = \begin{pmatrix} x_0(s) + x_3(s) & x_1(s) + ix_2(s) \\ x_1(s) - ix_2(s) & x_0(s) - x_3(s) \end{pmatrix}. \tag{14}$$

In view of the fact that $x_j(s) = 0$ for $j = 1, 2, 3$, one obtains from (13) and (14) the desired conclusion $x_0(s) = 2\tan(s/2)$.

A better understanding of the two-times and the redshift formulae is achieved at the cost of intensifying the calculations. This consists in looking at the effect of the temporal translation T_s on some small neighbourhood *NGR* (in the image of M in E) of the origin of M as a point of E instead of this effect just on the origin of M. This is done through the differential approximation dT_s of T_s. For a point $x = (x_0, x_1, x_2, x_3)$ other than the origin in *NGR* we no longer have $A = 0$ nor $x_j(s) = 0$ for $j = 1, 2, 3$ but we still have (11), (12) and (14).

The linear transformation dT_s maps the tangent space at the origin of M onto the tangent space at the image of the origin by T_s. The matrix of this linear transformation expressed in Minkowskian coordinates is the *Jacobian*

$$\left(\frac{\partial x_i(s)}{\partial x_j}\right) \tag{15}$$

evaluated at the origin of M. A computer calculation shows that this is the diagonal matrix all elements of the main diagonal being equal to $\sec^2(s/2)$.[15] This means that the approximate effect of T_s on any point x of *NGR* is to map it on a point whose Minkowskian coordinates are those of x magnified by the same factor $\sec^2(s/2)$. Perhaps surprisingly, this is reminiscent of BBC except that here Minkowskian time also is expanding. This

[15] Jean-Marc Terrier, an expert in the computer program *Mathematica*, has kindly verified this result as well as the formulae (8) and (12). The formulae for $x_j(s)$, $j = 0, 1, 2, 3$, given on p. 11115 of [92] appear to be wrong but, in any case, they are not needed here.

does not contradict the fact that T_s being an isometry of E it maps NGR isometrically onto its image. Wavelengths which are small relative to the radius of the universe may be assumed to fall within *NGR*. As a result, Segal concludes [92, p. 11115]: "In particular, wavelengths, after time s are observed as magnified by the factor $\sec^2(s/2)$."

Thus if λ is such a wavelength, it becomes $\sec^2(s/2)\lambda$ under T_s. As a result one obtains an equivalent proof of the redshift formula using the definition $z = \Delta\lambda/\lambda$ as follows

$$z = \frac{\sec^2(s/2)\lambda - \lambda}{\lambda} = \mathrm{tg}^2\left(\frac{s}{2}\right). \tag{16}$$

Similarly a small interval ds of cosmic time is magnified by a factor of $\sec^2(s/2)$ into a larger interval $dx_0(s)$ of Minkowskian time under the temporal translation T_s so that $dx_0(s)/ds = \sec^2(s/2)$. Integrating this relation immediately yields the two-times relation $x_0(s) = 2\tan(s/2)$ taking into account the initial condition $x_0(0) = 0$.

Going back now to the general case of a three-sphere of any radius r instead of the unit sphere, we note that all but the last map in (9) remain unchanged whereas the last one, $R^1 \times SU(2) \to R^1 \times S^3$, must be multiplied by r. As a result both x_0 and t ($= s$) must be divided by r in the formulae we have just established in the case $r = 1$. This immediately yields the original chronometric two-times and redshift formulae (1) and (2).

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