Cosmology in the Plasma Universe: An Introductory Exposition

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Abstract—Acceptance of the plasma universe model is now leading to drastically new views of the structure of the universe. The basic aspects of cosmological importance are: a) The same basic laws of plasma physics hold everywhere; b) mapping of electric fields and currents are necessary to understand cosmic plasma; c) space is filled with a network of currents leading to the cellular and filamentary structure of matter; and d) double layers, critical velocity, and pinch effects are of decisive importance in how cosmic plasma evolves. This paper reviews a number of the outstanding questions of cosmology in the plasma universe.

I. Introduction

Acceptance of the plasma universe model is now leading to drastically new views of the structure of the universe. Their main characteristics are given by Fälthammar [11]. Most important are the following:

- The same *basic* laws of plasma physics hold from laboratory and magnetospheric heliospheric plasmas out to interstellar and intergalactic plasmas.
- In order to understand the phenomena in a certain plasma region, it is necessary to map not only the magnetic but also the electric field and the electric currents.
- Space is filled with a network of currents which transfer energy and momentum over large or very large distances. The currents often pinch to filamentary or surface currents. The latter are likely to give space, as also interstellar and intergalactic space, a cellular structure [1, ch. II.10].
- A number of plasma phenomena, like double layers, critical velocity, pinch effect, and the properties of electric circuits, are of decisive importance. The phenomena mentioned have been known for decades (or even more than a century), but up to now they have almost systematically been ignored in cosmic physics. If they are taken into account, not only interplanetary space but also interstellar and intergalactic space must have a cellular structure [1, ch. II.10].

In the present paper we shall analyze whether these drastic changes in our picture of the universe have cosmological consequences.

When we discuss cosmic plasma we concentrate the attention on the low-density medium which fills space between massive bodies like stars, etc., that also consist of plasmas but of much higher densities.

Manuscript received April 19, 1989; revised August 17, 1989.
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IEEE Log Number 8933173.

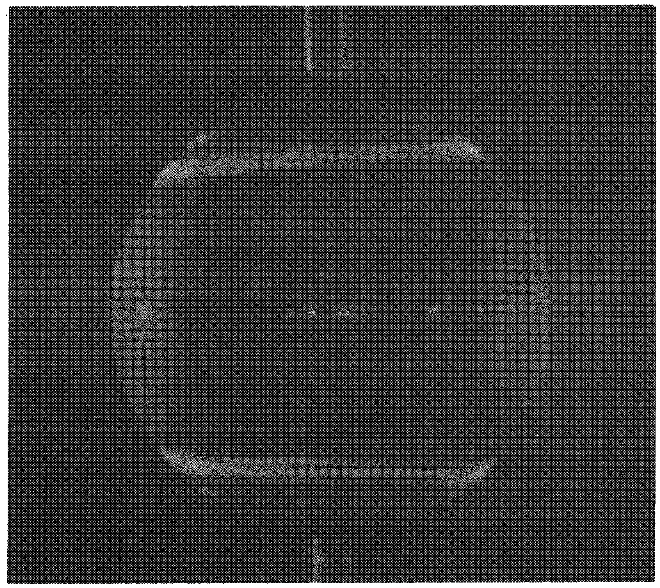

Fig. 1. Terrella experiment. Space is filled with plasma, which is prevented by the geomagnetic fields from reaching most parts of the Earth's upper atmosphere. It penetrates only two zones around the poles of the Earth: The auroral zone, which it makes luminous. This was demonstrated by Birkeland in his terrella experiment. It can also be seen on space photographs from above. The figure shows a terrella experiment by Block (reference [7]), who further developed the terrella experiment technique introduced by Birkeland in the beginning of the century.

II. Where Can We Observe the Cosmic Plasma?

As plasma fills almost all the universe, it should be easy to observe. However, the Earth's magnetic field prevents cosmic plasma from reaching most of the Earth's surface or upper atmosphere. Exceptions are the two auroral zones (cf. Fig. 1). As the Scandinavian third of the auroral zone (see Fig. 2) is the only one which has a tolerable climate, Scandinavia has for centuries been a privileged region for studies of the cosmic plasma. It was Anders Celsius who, 250 years ago, identified the aurora as an electromagnetic phenomenon by observing that a big compass needle placed on his desk in Uppsala changed its direction when the aurora appeared. By doing so he introduced a tradition of coordinating laboratory and space phenomena.

This tradition is still alive. One of its most prominent scholars was Birkeland, in Norway. The intimate collaboration between laboratory plasma experiments and iono-

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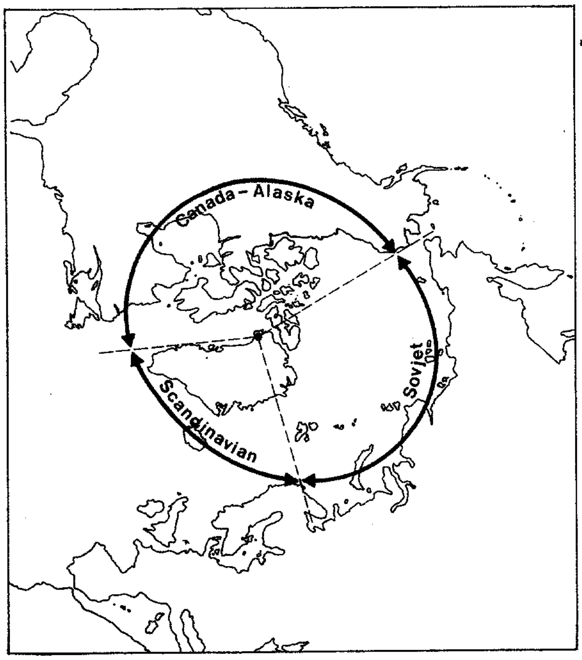

Fig. 2. The zone where cosmic plasma can reach the Earth consists politically of three parts. Climatic conditions make it preferable to observe the aurora in the Scandinavian zone, which has given a preference to space research in that area, where auroral research has a long tradition.

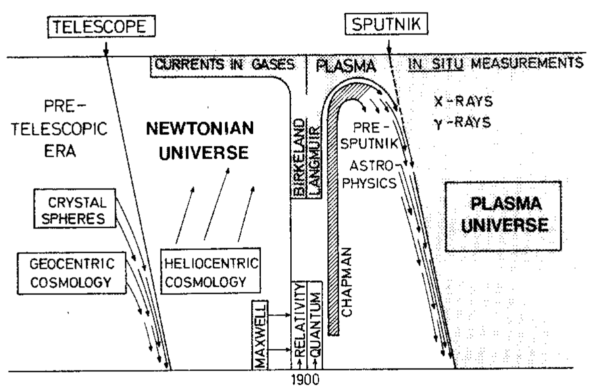

Fig. 3. Astrophysics in a nutshell. Three revolutions have affected the development of plasma physics in space: 1) The Copernican revolution; 2) the plasma revolution; and 3) the Sputnik revolution.

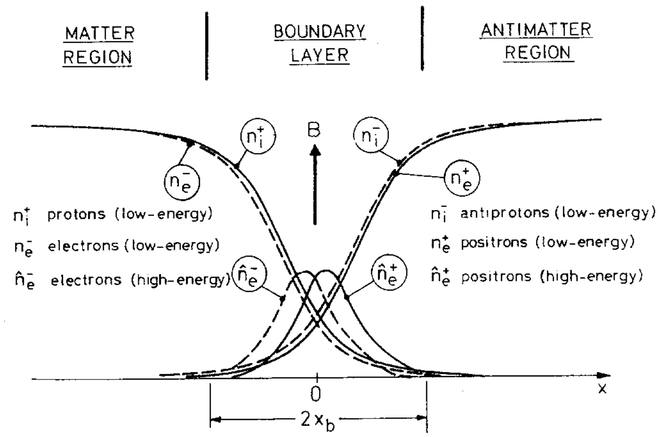

Fig. 4. Leidenfrost layer. At the boundary between a region of matter and a region of antimatter there is proton–antiproton annihilation which produces mesons that rapidly decay into 10^8 eV electrons and positrons. These form a very hot and extremely thin boundary layer separating the matter and antimatter regions. The radiation from this layer is so small that it is difficult to detect (references [14] and [15]).

spheric magnetospheric observations is now extended by the cooperative European space research in northern Scandinavia. The Swedish Viking mission has continued in the Scandinavia tradition of studying the properties of the plasma which fills the universe from the small-scale phenomena in the laboratory to the large-scale phenomena in galactic and intergalactic space. Cosmological theories based only on mathematical calculations should be treated with considerable skepticism (see Fig. 3).

III. Is the Plasma Universe Matter–Antimatter Symmetric?

As a consequence of Dirac's theory, Klein [12], [13] suggested that the universe might be matter–antimatter symmetric. A quarter of a century ago the cosmological interest was focused on the fight between the "Continuous Creation" and what was later called the "Big Bang." To both of these cosmologies a matter–antimatter symmetric universe was a disturbing concept that was important to get rid of. This was attempted by demonstrating that a homogeneous symmetric universe was out of the question, because it would be completely annihilated in a time of the order of millions of years.

As a starting point, Klein considered an essentially homogeneous universe, but neither he nor anybody else claimed that the present universe should have any similarity to a homogeneous model. This did not help. It became a "generally accepted" view that a matter–antimatter symmetry was out of the question. A number of attempts to correct this conclusion and open a free and unbiased discussion have been in vain. All such attempts have been met with the answer that no one has demonstrated in an unquestionable way the cosmic existence of antimatter. This is correct. On the other hand, no counterproof exists to demonstrate that the universe is not symmetric (see [16]). Cosmical physics is now seeing a general drift towards inhomogeneous models, and it is realized that homogeneous models are often not useful, even as first approximations.

The plasma universe model introduces important new arguments in this discussion.

From *in situ* space observations we know that there are current layers in space which separate space into regions with different magnetization, different temperatures and densities, and even different chemical compositions. Thus it has been found that space plasma has a tendency towards a cellular structure. This tendency has been observed throughout the regions at present accessible to spacecraft. As it is impossible to claim that such a basic property of a plasma (its tendency to produce cellular structures) should be confined to the regions presently available to spacecraft, one must conclude that space in general has a cellular structure (see the general discussion in [1, ch. VI]). The different chemical compositions on

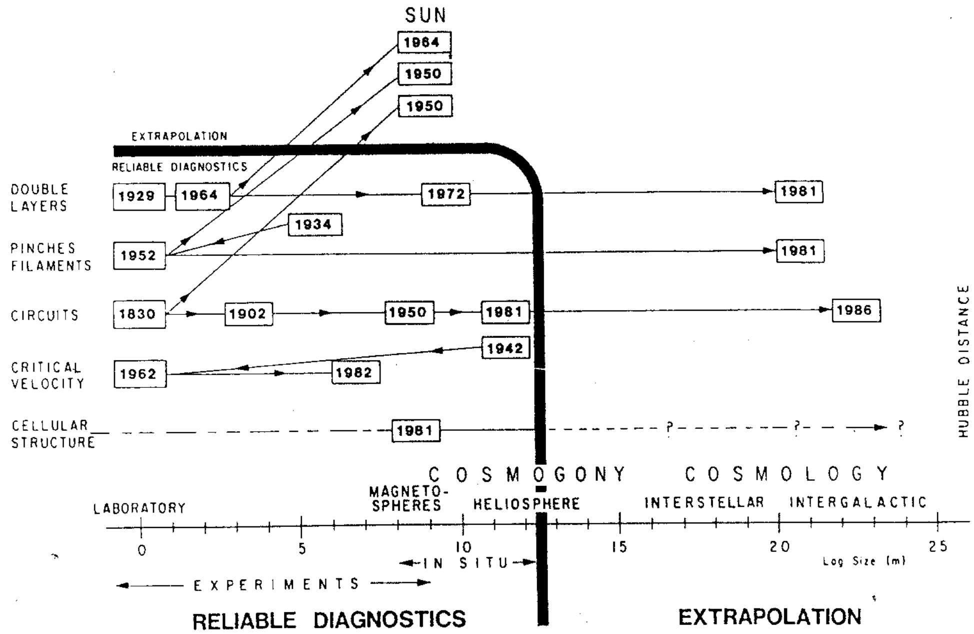

Fig. 5. The plasma universe consists of a reliable diagnostic region in which laboratory experiments and *in situ* measurements make a sophisticated study of a plasma possible. Outside the reach of spacecraft (black line), investigations must be based on a symbiosis between observation and the knowledge of plasmas gained from the reliable diagnostic region.

both sides of the magnetopause may have a counterpart in interstellar and intergalactic space, where there may be a difference in the kind of matter: Ordinary matter (koinomatter) on one side, and antimatter on the other. This conclusion should be combined with the theory of Leidenfrost layers as analyzed by Lehnert [14], [15, fig. 4]. It is important to note that such layers—if static—may emit a negligible amount of radiation. They should be depicted as being thin, very hot layers of almost complete vacuum.

The result of such discussions is that we have little reason to question that in the present state of development of our concept of interstellar and intergalactic space the plasma universe could very well be matter–antimatter symmetric (see [1, ch. VI]).

IV. Structure of the Plasma Universe

The result of extensive discussions about the structure of the plasma universe is depicted in Fig. 5. We can distinguish between two categories of regions: One is the "reliable diagnostic region," comprising laboratory plasmas and those regions of the magnetospheres and the heliosphere that are accessible to spacecraft. The other part of the universe comprises all other regions, i.e., those outside of the outer planets and the Sun, where our knowledge of the properties of plasmas depends on extrapolation from results obtained in the reliable diagnostic regions (see Table I and Fig. 5).

TABLE I
Properties of Magnetized Plasmas (reference [3])

	FLUID PLASMA (Magneto-hydrodynamic)	PARTICLE PLASMA (Collisionless)
General Properties	Similar to fluid	An assembly of particles in ballistic orbits
Motion in electric field	Thermal motion superimposed by electric field drift	Ballistic orbits in magnetic and electric field
Velocity distribution	Essentially Maxweilian	Often anisotropic. Has a tendency to generate very high energy particles: magnetosphere keV solar atmosphere MeV GeV interstellar space possibly 10^{14} or more
Exists in:	solar, stellar photospheres Ionospheres Comet coma	Solar corona Active regions in magnetospheres Comet tails Interplanetary, interstellar, intergalactic space
Radiates	Thermal (essentially visual) radiation No X-rays or γ-rays	X-rays, γ-rays (by collisions with residual particles "Noise" generation, especially in connection with production of high-energy particles
Energy transfer	Local theories correct	Only global theories correct because currents transfer energy over large distances (often much larger than size of ballistic orbits)
Frozen-in magnetic field	Yes	No
Energy release through magnetic merging	Possible	No.

V. Does α Centauri Consist of Matter or Antimatter?

How little we know about the universe outside the reliable diagnostic regions can be demonstrated by asking whether one of our closest stars, say α Centauri, consists of matter or antimatter. Of course, "of matter" is the obvious reply, but how can this be proven? An antimatter star should emit the same spectrum. Certainly the sign of the rotational Faraday effect is different for electrons and positrons, but as we do not know the sign of the magnetic field, this does not help.

It may be suggested that if the solar wind (from our Sun) approaches α Centauri and that this star also emits a

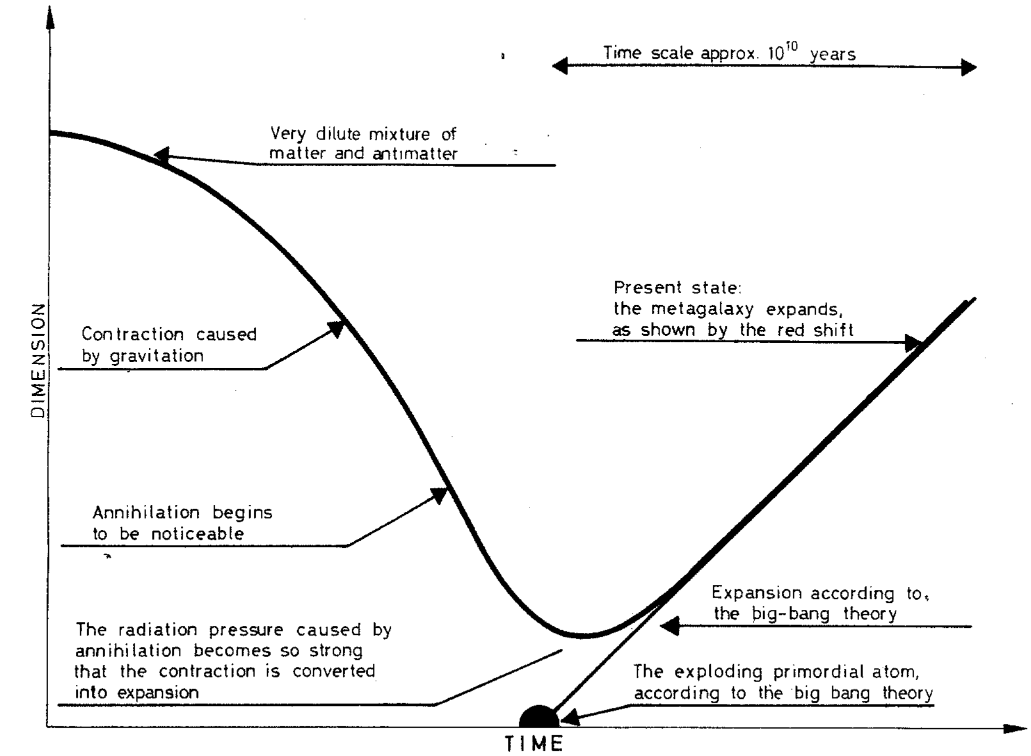

Fig. 6. Evolution of the metagalaxy in Klein's model (see reference [1, fig. VI.3]). The time scale before the turning should be enlarged.

solar wind, collisions between these two winds would give rise to violent annihilation with detectable gamma-ray emission. However, there is plenty of room for a large number of Leidenfrost layers between our Sun and α Centauri.

The absence of large quantities of antiparticles in the Cosmic Radiation (CR) is another argument. If the sign of primary cosmic rays were known for energies $>10^{14}$ eV, this would be a strong argument. However, the sign of primary CR is known only up to less than 10^{11} eV. Such particles have Larmor radii, which are very small, and all the CR in this energy range could very well be generated inside an extended heliosphere.

So once again we do not know enough to exclude a Dirac–Klein symmetry. On the other hand, there is not decisive observational argument in favor of antimatter. (In [1, ch. VI] this problem is discussed in some detail.)

Hence it must be considered legitimate to study the consequences of both hypotheses: Is the plasma universe symmetric, or does it consist of exclusively ordinary matter? As the second alternative is treated in a gigantic literature, it is appropriate that we here concentrate on the first alternative. If this is correct, an unprecedented change in astrophysics would occur.

At the American Geophysical Union 1988 Fall Meeting in San Francisco, attention was drawn to the enormous difference it would make to astrophysics in general if the α Centauri consists of matter or of antimatter. A symbolic award was proposed to be given to the scientist who could prove which of these alternatives is correct.

VI. Klein's Cosmological Model

Klein [12], [13] makes the natural assumption that the Dirac matter-antimatter symmetry is valid also in the universe. (Klein used the old term "metagalaxy" because he does not take for granted that the region of space we observe at present is the whole universe.) He assumes that our metagalaxy "initially" was in the form of a gigantic homogeneous cloud of ambiplasma—koinomatter (from greek *kionos*, meaning ordinary)—and antimatter mixed homogeneously (Fig. 6). Its density is so extremely small that annihilation is negligible. This sphere contracts under the action of gravitation. When it has reached a size of perhaps $10R_H$ (R_H = Hubble distances), annihilation becomes important and produces a force opposite to the gravitation, which slows down the contraction. Annihilation increases with increasing density, and eventually it is large enough to convert the contraction into expansion. After the turning which may take place at, say, $0.1R_H$, the sphere expands again. This expansion is identical with the Hubble expansion. Some 10 percent is annihilated at the turning and converted into kinetic energy of the Hubble expansion and different kinds of radiation—among them cosmic microwave background radiation.

VII. Prophetic or Actualistic Approach to the History of the Universe

When discussing how to approach the origin and evolution of the solar system, G. Arrhenius (private communication), who is a geologist, pointed out that when the geological history of the Earth is studied, the actualistic approach is very valuable. This principle says that the present is the key to the past. In other words, we should not approach a historical problem in science by making a guess about how the conditions were in a certain region several billion years ago, because the probability that such a guess is correct is very close to zero. Instead, we should start from the present conditions.

During the ages innumerable prophetic guesses have been made. They have survived to our times only in cases when the guesses have been claimed to derive from divine inspiration. This means that the guesses must have been made by great religious prophets. Hence we find such guesses included as important parts of holy religious scriptures.

Hence, there are two different ways of approaching the prehistory of the present state of the plasma universe, or part of it.

A. The Prophetic Approach

A guess is made about the state very long ago, and this is made credible by prophetic authority. This approach often assumes that there was a "creation" at a certain time, and it is often claimed that we know more about this event than about more recent times.

B. The Actualistic Approach

We start from the observed present-state and try to extrapolate backwards in time to even more ancient states. From this follows that the further backwards we go, the larger is the uncertainty about the state. This approach does not necessarily lead to a "creation" at a certain time, nor does it exclude this possibility. In principle, it is also reconcilable with a universe which is "ungenerated and indestructible," as Aristotle expressed it.

VIII. What Does the Hubble Diagram Tell Us?

The Hubble diagram is usually plotted on a logarithmic scale. Taking account of the great uncertainties, it is reconcilable with a picture of a universe in which the expansion derives from a "Big Bang" at a singular point. However, this does not mean that the Hubble diagram proves this.

First of all, the observed red shifts do not necessarily derive from a longitudinal Doppler effect. But even if we assume that they are caused by a Doppler effect, the reconstruction of the orbits of the individual galaxies leads to the diagram which merely shows that once they were much closer together. In fact, it seems legitimate to conclude that the metagalaxy (the "universe" according to the "Big Bang" hypothesis) once had dimensions of about $0.1 R_H$, but it seems to be not legitimate to conclude that it was even smaller. For a discussion of this, see [1, ch. VI], and also the discussions by Bonnevier [8].

IX. A Bigger "Big Bang"

Let us for a moment eliminate a number of "prophetic" *ad hoc* hypotheses; i.e.: a) That there are some orders of magnitude of more mass in the universe than is really observed ("missing mass"); b) that the Hubble expansion was caused by unknown effects at a singular point; c) that the present universe does not contain an appreciable amount of antimatter; and d) that cosmology can be treated by homogeneous models.

We try to construct a universe such that: i) It is essentially matter–antimatter symmetric; ii) the Hubble expansion is caused by well-known processes (among them, energy release by annihilation) in a region of 10^9 light years (a bigger "Big Bang"); iii) it does not contain large quantities of missing mass; and iv) it is highly inhomogeneous and has a cellular structure.

What is said above does not lead to the conclusion that we accept the Klein cosmology as it was presented.

X. How to Approach Cosmology

Klein [12], [13] bases his analysis on the assumption that very long ago the metagalaxy consisted in an extremely large sphere of matter and antimatter. This classifies his theory as "prophetic." However, the picture he gives of the evolution after the turning (the bigger "Big Bang") can probably serve as a guideline to an evolutionary actualistic approach. Whether this is correct or not can only be found if the observed present state of the universe is used as a basis for a reconstruction of increasingly old states. It is reasonable to use well-established laws of nature as a first approximation. The enormous mass of observations should be subject to an unbiased application of modern plasma physics as derived from extrapolation of studies of the reliable diagnostic regions, etc.

The primary aim should be to try to reconstruct evolutionary history back to the "turning" (Fig. 6). If this attempt runs into difficulties, the time is ripe for drawing conclusions about missing mass, etc.

XI. Reconstruction of the Evolutionary Processes

Space research has resulted in a model of the "plasma universe" (see Fig. 5). In [9] and [10] it is shown how *in situ* observations in the Earth's magnetosphere can provide a key to the understanding of astrophysical and cosmological phenomena in the plasma universe.

In the plasma universe not only the present state but also its prehistory is of importance. As discussed in Section VII above, there are two different types of approaches, called "prophetic" and "actualistic." It has been proved that in cosmogony the actualist approach is preferable [2]–[4], and a number of prophetic approaches are now falling down. Because the galactic problems are similar to the ionospheric–magnetospheric problems, this approach is likely to be also preferable in this field. However, this does not mean that we necessarily should accept it in the case of cosmology.

We have given above a brief summary of the Klein cosmology. The conventional "Big Bang" is too well-known to need a recapitulation. Let us first state the aspects where there is agreement between the two approaches. Both attribute the Hubble expansion to a "Big Bang," and both are prophetic theories. Further, as Fig. 6 shows, they both give a similar Hubble from between the present time and back to about $0.1\,T_H$ (T_H = the Hubble time). However, this does not mean that the properties of the expanding plasma are the same. These properties are derived from the general properties of the early-time plasma of the two prophetic theories.

As the cosmological problems are outside the "reliable diagnostic region" in Fig. 5, it is appropriate to derive the properties of the expanding plasma after 0.1 T_H from the plasma universe model. Hence we should apply an actualistic approach to this part of the Hubble expansion and leave the discussion of what happened before $0.1\,T_H$ for later discussion. If this extrapolation seems reasonable, i.e., if we succeed in a reconstruction of the state at $0.1\,T_H$, we could use this as a basis for a discussion of earlier periods, but this is outside the aim of this paper.

XII. Conclusions

What has been said above means that we should try to adopt the "Big Bang" cosmology to the plasma universe model in two different ways. Both may run into difficulties, and only a free and unbiased discussion can clarify on how to deal with these.

The first one is that we start from the traditional "Big Bang," which necessarily leads to a number of difficulties. It is basically a "prophetic approach." The second approach starts from the present state of the plasma universe and attempts to reconstruct earlier states. Hence it is essentially an "actualistic approach." This certainly contains a number of uncertain and doubtful points. An essential point is that the Hubble expansion was caused by annihilation in a large region (10^9 light years). We call this a bigger "Big Bang." We leave the early-time part of the Klein cosmology—which is prophetic—outside the discussion.

Acknowledgment

This paper—as well as most of my papers—is due to an intimate collaboration with Prof. N. Herlofson.

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