The Cosmological Principle: Theoretical and Empirical Foundations

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The idea of the ("perfect") cosmological principle (CP), *viz*. that the Universe presents the same aspect from any place at any time, is traced to the ancient Greek philosophers, who also suggested how such a cosmic order might work. The antithesis of this view, *i.e.* the Aristotelian-Ptolemaic world-picture, was to become the hallmark of the Dark Ages. The Copernican revolution constitutes the first step by science in a modern direction, and the advance of science is thus seen as a succession of world pictures, all centred on local systems, in a hierarchical progression. We demonstrate that the prevailing picture of the Universe as an evolving system is still trapped in a local mode of thinking: the Copernican revolution is unfinished.

It is inferred on philosophical grounds that the Universe as a whole is uniform and non-evolving: whether this is valid for the observed portion of the Universe, the metagalaxy, has to be settled by empirical means. If it is, the metagalaxy can be said to furnish a representative sample of the Universe, while a genuine cosmology, defined as the study of an entity fulfilling the CP, would become an attainable objective. In methodological terms, this implies that observers' attention could be turned from high-redshift objects to more accessible nearby objects, while the trend toward high technology could be supplanted by more intensive analysis.

In the empirical section, we show that both the spatial and temporal aspects of the CP are probably fulfilled in the metagalaxy. The possibility of evolution on the cosmic scale is examined through two classes of evidence: evidence for expansion and evidence for changes in the average properties of discrete objects over cosmic distances. On both counts the Universe appears as non-evolving.

Concretely, the task of constructing a cosmology incorporating the CP requires that modern science complete the still unfinished Copernican revolution. The empirical part of this task is briefly outlined. One theoretical approach, the “quasistatic” model, is presented mainly as an introduction to the problems encountered in the CP universe. The chief observational problems – redshift, microwave background, Olbers’ paradox (and its gravitational analogue, macroscopic structure), the passage from hierarchical organization to homogeneous distribution on the cosmic scale and cosmological stability – are interpreted in terms of coupling between the gravitational and electromagnetic interactions. The apparent paradox of a universe that does not evolve, even though all its discrete constituents evolve individually, is resolved by seeking effects that contradict the known local evolutionary effects of cosmic parameters such as density distribution, angular momentum, morphological type, photon-baryon ratio and element abundances. These parameters are shown to be unvarying on the large scale. The equilibrium processes corresponding to these parameters may be influenced by global factors (in particular interactions of cosmic masses) and local factors (especially activity in galactic nuclei). Equations of state that characterize an equilibrium universe are presented. Finally, the implications of the cosmological principle and quasistatic cosmology for

general physics are discussed. Important formulations will be needed in most branches of physics, including our concepts of space and time. The cosmological facts underlying the CP point directly toward a unified physical theory.

I. Introduction

1. The topic of the present review is the cosmological principle in the form known as the “perfect cosmological principle”, which formed the philosophical basis of the steady-state cosmology put forward by Bondi, Gold and Hoyle. Since this is the genuine expression of the cosmological viewpoint of *homo sapiens*, and the prefix “perfect” thus has only historical value, I shall simply refer to the “cosmological principle”, abbreviated as “CP”.

The CP states that, apart from local irregularities, the Universe presents the same aspect from any place at any time (Bondi, 1960). In the restricted cosmological principle of the standard model, only the spatial dimension is isotropic.

2. Bondi (1960) has presented the following arguments in favour of the CP and the steady-state cosmology, which assumes recession of galaxies and continuous creation of matter to ensure constant matter density: (a) the creation problem is brought within the scope of physical inquiry, not handed over to metaphysics; (b) the time-scale difficulties are avoided; (c) the evolutionary effects of the standard model, which are entirely unknown, need not be considered; (d) there are no ambiguities in interpreting the results of cosmological tests, such as the Hubble diagram, the angular diameter-redshift test and galaxy counts; (e) by contrast to the standard model, in which a variation of physics due to the changing universe has to be fixed arbitrarily, conventional physics can be used anywhere and at any time in the CP; (f) the CP presents a particularly simple picture of the

Universe; (g) if the CP is not valid in the real universe, progress in cosmology will be infinitely more difficult.

These arguments are also valid in a quasistatic, *i.e.* non-expanding, cosmology. However, here the notion of "creation of matter" has a meaning quite different from that ascribed to it by Bondi *et al.* In Section III, further arguments on behalf of the CP and its philosophical implications will be discussed. The historical development of the idea of the CP is dealt with in Section, II, with comments on its current status. Observations relevant to the CP are discussed in Section IV, and an approach to theoretical problems arising from the CP is outlined in Section V.

II. History

3. The first known statements involving the idea of the CP, in both the restricted and the general form, can be traced to the ancient Greek materialist philosophers. These ideas come to us through the Roman poet Lucretius Carus (96-43 BC) in his great poem *De rerum natura*. Lucretius wrote (Rouse, ed. and trans., 1975): "The universe then is not limited along any of its paths... Nor does it matter in which of its quarters you stand: so true is it that, whatever place anyone occupies, he leaves the whole equally infinite in every direction." And further: "... unless matter had been everlasting, before this all things would have returned utterly to nothing"; and "Nor can any power change the sum total of things; for there is no place without into which any kind of matter could flee away from the all; and there is no place whence a new power could arise to burst into the all, and to change the whole nature of things and turn their motions."

The Greek natural philosophers also had ingenious ideas about how this kind of cosmic order could come about, ideas which are relevant even today for the interpretation of the CP. These include:

struggle and equilibrium of opposites in nature, as proposed by Heraclitus (Volkov 1974) and indicated in Lucretius's poem for earthly phenomena; birth and death of cosmic bodies (Anaximander and other pre-Socratic materialists); origin of all that exists from apeiqom, the infinite, indefinite nature (Anaximander); growth of the cosmic bodies from a chaotic phase (*e.g.* Lucretius); evolution of all that exists, including humanity, society, culture (Lucretius); character of space and time (Lucretius); the atomic principle (Leucippus and Democritus); and the hierarchic structure of matter (Anaxagoras).

4. The antithesis to the CP, the Aristotelian-Ptolemaic world view, was also elaborated in antiquity. In this model the world was created by God as a habitation for mankind. The earth was at the centre, the moon, sun and five planets revolved around it, each fixed in its own crystal sphere. Beyond this there was a sphere of fixed stars, one for the *Primum Mobile*, and finally, the Empyrean Heaven. This highly unscientific picture is rooted in theology and anthropocentrism, closely follows outward appearances, is rigid and lacks dynamics, and is extremely complex. By the end of the 15th century, the model required more than 80 different crystal spheres, and even this was not enough to "save appearances". Only the modern standard model, which demands an increasing number of "epicycles" to avoid breakdown, can compete with the Ptolemaic picture in complexity: it shares many common features with its Mediaeval predecessor.

The geocentric view of the cosmos coincides directly with the lengthy stagnation of Western civilization during the Dark Ages. This was an age of faith, not of science. Science was not even needed, since divine influence explained all aspects of reality. The talented individuals of the time devoted themselves to theological issues. Comfortably ensconced at the centre of the universe, European civilization had no cause for doubt or suspicion.

5. The aboriginal peoples, sensing the close ties between the cosmos and their daily activities, developed their own world pictures. Though less sophisticated than the products of Mediterranean antiquity which became the litany of the Christian church, they were in some respects more correct. From indirect reports about the non-anthropocentric views of primitive peoples we can conclude that their traditions contained the rudiments of such cosmological concepts as infinity, eternity, the origin and evolution of the earth, sun, moon and stars, the true nature of the Milky Way, and past and future catastrophic natural events. (Jaakkola 1989, Harva 1933, Clube and Napier 1982). Wherever they are found, these anticipations are more advanced than Ptolemaic thinking, and even stand above certain present-day speculations. We have anthropological, archaeological and philological evidence (Harva 1933) that primitive man's view of the cosmos may have been a quite realistic one (Jaakkola 1989), and this is hardly surprising considering the pragmatic nature of stone-age economies.

6. The effects of the Aristotelian-Ptolemaic world-picture, as well as its breakdown, give us insights into the historical significance of the cosmological world-picture at any time, including the present. If the cosmological picture in a given era is shaken, the whole corpus of thinking comes crumbling down. The publication of *De Revolutionibus Orbium Caelestium* in 1543 struck a vital nerve of Mediaeval thinking. Suddenly, people were no longer living in the Creator's pocket, and the Universe no longer whirled around them, while their habitat, earth, was relegated to an undistinguished position as one of many planets moving through empty space around another centre.

The new situation issued a challenge to the minds that had lain idle during the Middle Ages. The Copernican revolution signals the beginning of science in the modern sense. It was at the same time the first, the longest and the hardest step up the staircase of the evolution of science. However, the top of the staircase has yet to be reached, for this requires that the cosmological principle be embodied in fundamental theory – the topic of the present paper.

It is said that the first printed copy of *De Revolutionibus*, on which Copernicus had worked relentlessly for more than 30 years, was brought to him on his deathbed. This is one of the most dramatic moments of the movement of ideas: a dying titan on the ruins of a collapsing empire hands the torch to another generation, to be carried into a new world.

7. The second step along the staircase, after the adoption of the heliocentric picture, came shortly afterward. Only a few decades later, Giordano Bruno stated that the sun is an unexceptional star among others, while innumerable inhabited planets revolve around these stars. In 1600 Bruno was burned at the stake.

The intellectual battle over the Copernican principle raged on. Using his telescope, Galileo, the founder of experimental physics and instrument observation, discovered mountains and "oceans" on the moon, just like those on earth, identified the moons of Jupiter, resolved details on the surface of the sun and found that the Milky Way was made up of stars like our own sun. All these discoveries pushed the earth farther from the centre of the universe, and hold an honoured place in the history of the CP. Galileo was investigated by the inquisition and placed under house arrest for decades, while his works were included in the list of forbidden books.

8. While the chain of subsequent pictures of the world centred on local systems at various levels of hierarchy forms the "outer" history of science, the discovery of the physical laws, the generalization of forms of motion within each level, forms the "inner" history. These two aspects of development are closely connected with one another, and advance in tandem. Galileo's, Kepler's and Newton's laws of

mechanics and planetary motion integrated the new empirical findings into a new conceptual framework. Yet the Copernican ideas were slow to penetrate the minds of scholars and laymen alike, and we are justified in saying that the process is far from incomplete.

9. The next step, beyond the galactocentric view, has been more painful and slower. It was two centuries before it was realized that the nebulae seen with telescopes in both directions outside the bright band of the Milky Way are galaxies just like our own system. The correct view was suggested independently by Thomas Wright, Kant and Lambert in about 1750 (North 1965), and it was also adopted by William Herschel (Dreyer 1912). However, the world picture commonly assumed in the 19th century was a single system, the island universe of our Milky Way system, and the elliptical and spiral nebulae were thought to be satellites of that system. Though objections were made to this model (Jaki 1972), most astronomers were content with it.

Even after Hubble and Lundmark had confirmed the extragalactic nature of the nebulae in the 1920s, our galaxy was still thought to have unique properties (its diameter was supposed to be larger than other galaxies). Finally, in 1952, Baade (1952) showed that there was an error in the intergalactic distance scale caused by interstellar extinction of light. Consequently, right down to modern times, even the simplest elements of the Copernican principle had not completely penetrated the scientific world.

We might therefore ask whether careful attention to the lessons provided by the history of natural philosophy and cosmology might have abbreviated this arduous passage. The same question is justified today in conjunction with the present status of the genuine (*i.e.* strong) CP.

10. It was Hubble who first made contact with a truly cosmological distribution of matter. In 1926 he made number counts

of galaxies from 12.7 m to 16 m and found the slope of the relation $\log N \propto bm$, where $b = 0.6$, which is expected for a distribution that is uniform in depth. Shortly afterwards, he wrote (Hubble 1934): "*There are as yet no indications of a super-system of nebulae analogous to the system of stars. Hence for the first time, the region now observable with existing telescopes may possibly be a fair sample of the universe as a whole.*"

The importance of this observation has hardly ever been noticed. Yet in a sense, it is the gateway to modern cosmology. If it had been taken into account by the scientific community in a consistent manner, it would have meant the final step in the pyramid of science, *i.e.* the beginning of the study of its ultimate object, the cosmological distribution of matter.

11. But science missed this opportunity. It did not choose the route pointed to by Hubble's discovery, Zwicky's physical interpretation of the redshift effect (Zwicky 1929) and Einstein's intuitive introduction of the "cosmological constant" in a static relativistic world-model (Einstein 1919). Incurable theorist that he was, he applied this model to the distribution of stars despite all the naked-eye evidence. Science chose a more tortuous route: that of Abbé Lemaître, Eddington, Jeans, Gamow and others. This route was based on the all too hasty interpretation of the redshift as a Doppler effect, despite the fact that the latter is a symmetrical effect while the former is asymmetrical. In yet another false scent, universal expansion was seen as the cosmological manifestation of the second law of thermodynamics. Third, a dangerous trend had emerged in physics: people began to think that everything that is possible in mathematical models must also be possible in physical reality, and unstable solutions found for Einstein's equations were regarded as a theoretical prediction of expansion. It was not noticed that what was observed ("expansion", *i.e.* redshift) was exactly the opposite of what was predicted by the

fundamental theory of gravitation. Expansion then demanded an extra *ad hoc* interpretation, the Big Bang, which stands outside the whole domain of physics.

12. Scientists like Hubble, Humason, Mayall and Zwicky, who, following in Slipher's footsteps, made measurements of z for a large number of galaxies and therefore had the closest contact with the actual redshift effect, were far less convinced of expansion than the theoretical cosmologists were. Hubble made his classical tests of the expansion hypothesis with the result that an expanding model can be obtained only as a forced solution (Hubble 1937). He also investigated the possibility of cosmological evolutionary effects, and found no empirical evidence to support it. Zwicky, who had examined the diameters and structures of nearby and distant clusters of galaxies, adopted the view of a non-expanding, non-evolving universe (Zwicky 1957). Hence, while the narrow, spatial aspect of the CP was adopted by the large majority of scientists, the genuine CP (involving time as well) has been kept alive by a small but eminent minority since the first decades of this century.

13. In the late 1940s, Bondi, Gold and Hoyle (Bondi and Gold 1948, Hoyle 1948) put forward their steady-state cosmology. After Einstein's original model, this is the second modern model based on the CP. While much of its philosophical basis remains valid, the notion of "continuous creation" violates the conservation principle and is unacceptable from the materialist point of view. Empirically, it cannot survive the modern empirical tests of the expansion hypothesis (Jaakkola 1983, 1986, 1988a). Once a serious alternative to the standard theory, during the 1960s the steady-state cosmology was generally abandoned – even by its authors – mainly because of its apparent disagreement with observations, in particular radio-source counts (Ryle 1968). However, a re-examination of the empirical arguments shows that they are probably invalid (Jaakkola, Moles and

Vigier 1979). Whatever the case, in the author's opinion, the hypothesis of expansion and continuous creation remain serious drawbacks of the theory.

14. New theories and tests of a non-expanding universe have been developed since the 1950s (Born, Finlay-Freundlich), and in particular since the beginning of the 1970s (see Pecker 1976). With few exceptions, these theories adopt both aspects of the CP. The models are based on various theoretical hypotheses, such as de Broglie's wave mechanics with nonzero-mass photons and a redshifting medium consisting of light neutral bosons (Pecker 1976), a material ether (Pecker and Vigier 1988), elementary quanta composing photons and elementary particles (Broberg 1987), generalized Einstein redshift with a nonzero-mass photon (Keys, personal communication), spontaneous transfer of photon-energy to the vacuum (Kipper 1973), properties of time (Segal 1976, Abramenko: personal communication), a Machian wave theory of gravitation resulting in an absorbing background (Roscoe 1988), electro-gravitational coupling (Jaakola 1983, 1987), Mach's principle (Jaakkola 1987, Ghosh 1988, Hoyle and Narlikar 1964). It should be noted, however, that Hoyle and Narlikar's theory violates the CP.

What is especially noteworthy is that the same result emerges from so many directions - the universe does not expand. A correct theory will undoubtedly eventually be developed, perhaps as a coalescence of these earlier suggestions.

15. The hierarchical model, according to which each system belongs to a larger scale system, though it may or may not fulfil the temporal aspect of the CP, does not fulfil the spatial condition. During the 19th century it was put forward as a solution to Olber's paradox in an explicit formulation by Charlier (1908 and 1922), and has been re-examined by de Vaucouleurs (1970) and (1988). This model will be discussed in the following sections.

16. The currently fashionable inflationary model, developed to solve certain difficulties in the standard model, is of some interest here. It suggests a concept of the cosmos (not a new one) in which our expanding universe might be one member of an extended system. An inference from this idea, that the totally of such systems might fulfill the CP, may not be so far-fetched. However, the very idea of a cosmic inflation is so extremely speculative that such an approach to the CP is instructive only as a snapshot of present-day cosmology rather than a description of physical reality.

17. This historical section, which has necessarily been fragmentary and no doubt lacking important information, ends at the phase in which the spatial aspect of the CP is generally, in more or less consistent manner, accepted as the basis of cosmological theory. The temporal aspect, on the other hand, is considered by only a very small minority. Since the two aspects are intimately connected to one another, and since both must be contained in a genuine CP (as we will show in the next section), the situation we now face is highly anomalous. Obviously, the Copernican revolution, the modern manifestation of which is the CP, has not yet been embraced by the scientific community.

III. Philosophical considerations

18. What does the expression “cosmological” mean, and what function does a “principle” fulfill in science. “Cosmological” means something which is valid globally and universally. It is the opposite of “local”. A study of any single system cannot be equated to cosmology in the proper sense: this is the key point in the history we have sketched in the previous section.

Every individual system evolves. This is true even for such an apparently dead system as the moon, which, if nothing else, flies away from the earth 4 cm a year, and thus undergoes change as a component of the earth-moon system.

19. The universe is not a single system; in fact, it is not a system at all. Physical systems are not homogeneous: they contain central bodies, other different constituents, density gradients, *etc.* The universe is homogeneous, structureless. It is more than the sum of its contents. It is not analogous to individual systems – with only a quantitative difference. Nor is it a supersystem. The universe is different in a fundamental, qualitative sense. This is the fundamental lesson that has to be learned before we embark on cosmology. The basic difference of the universe should also be reflected in the way we study it. The CP is this reflection.

It would be unwarranted to infer that the universe evolves together with its constituents. A good analogy here is the fact that while individuals age, the mean age of people living on earth does not increase one year every year.

20. Can one advance philosophical arguments as to the question of the evolution of the universe?

The view taken by Lucretius and other ancient philosophers was briefly presented in the first section. The question has also been touched upon by later philosophers, of whom we will consider three (Jovstshuk *et al.* 1975, Russell 1946).

Baruch Spinoza taught that there is only one unique substance, nature, which, *causa sui*, is its own nature. The very essence of this substance excludes any variation. The substance is eternal and infinite, cause and effect at the same time, the essence and the existence. Spinoza’s substance is equivalent to our concept of the universe, and the non-existence of diversity excludes its evolution. The world of moods, of finite, diversified individual beings, is something different from the substance of the world.

Hegel's often obscure "absolute idea", in some contexts, approaches the concept of "nature". It exists without beginning and without time. Without neglecting the diversified changes in nature, Hegel considered them as belonging to eternal circulation in the cosmos. He was certainly no natural scientist: "There is nothing new under the sun, and the manifold play of nature with the forms makes me tired" (Hegel 1928). Although this is not a dialectical conception of evolution, and although Hegel is of course in many respects an idealist philosopher, his denial of evolution of nature as a whole, often incorrectly criticized from the standpoint of materialism (Jovstshuk *et al.* 1975), is not the hallmark of an idealist.

Engels had a clear opinion on this question. In the *Dialectics of Nature*, he wrote, in an elevated style that suits the topic perfectly: "... we have the certainty that matter remains eternally the same in all its transformations, that none of its attributes can ever be lost, and therefore, also, that with the same iron necessity that it will exterminate on earth its highest creation, the thinking mind, it must somewhere else and at another time again reproduce it." (Engels 1972). And Engels emphasized that indestructibility of motion (of matter, of nature, of the universe - T.J.) should be seen not only in the quantitative but also in the qualitative sense.

In the same way that Spinoza compared the relationship between finite individual moods and infinite substance to the relationship between the points of a line and the line itself, and remembering any motion can be described mathematically in a fixed system of coordinates, the physical universe can be seen as the fixed frame of reference within which motions and evolutionary effects occur.

On the most basic level, the question of CP and the steady-state character of the universe is a philosophical one in the same sense as the question of the existence of matter independent of human consciousness. Answers to these questions divide philosophy into two antagonistic camps: materialism and idealism.

21. The question of the validity of the spatial aspect of the CP can be transformed into the question of the eternity of the universe. If the universe is infinite in time in both the past and future directions, there would already have been enough time for a one-way evolution to lead to the limiting values of cosmic parameters, enough time for the "heat death of the universe". The eternity argument gives us one more reason to use the CP in cosmology: the universe is not dead.

22. The implication of the above discussion is that cosmology must be defined as the study of an entity that fulfills the CP, an entity without structure and without evolution. When so derived, the CP indeed appears as a "principle", as a categorical condition of cosmology. It is a logical statement with a philosophical foundation, defining the exact object of cosmology among the objects of the other sciences.

The CP as a necessary and sufficient condition of the object of cosmology gives this science a unique position. The two aspects of this principle cannot be valid for the objects of any special sciences. The concrete realization of cosmology so defined bestows on it the status of a general natural science, having its own field of study within which the results of the special sciences can be applied.

23. Science is a human activity, and the various sciences, scientific methods and concepts can be subject to particular requirements, definitions, limitations and principles, which can be agreed upon or at least discussed by practitioners. However, no demands can be made upon nature—much less the cosmos as a whole. Whether the CP is valid in the metagalaxy is an empirical question, not a philosophical question. We shall try to answer the empirical question in Section IV.

24. Our finding is that an affirmative answer to this question is probably correct. What are the philosophical consequences of this

result? The first and most important implication is that the *the metagalaxy is a representative sample of the whole universe*. The observed properties of matter can be inferred to be valid everywhere, even beyond the scope of our observations.

If the metagalaxy did fulfill the CP but were not a fair sample, it would be a single local system outside of which there would be other systems with other properties. Yet no single system lacking structure and evolution can exist. Of this we have sufficient evidence from the observed hierarchical levels in the structure of matter: at each level we find differentiated structure and correspondingly differentiated interactions, motions and evolutionary effects.

25. The discovery that the metagalaxy is a representative sample of the universe opens the way to cosmology. We can safely extrapolate from this sample to conditions in the universe as a whole. By examining the finite, we can examine the infinite. Infinity is no longer a field of mysticism and a purely abstract concept: it becomes a topic of concrete scientific study. In the course of the development of science, people will learn to know infinity, understood as matter as a whole. Hegel's idea of absolute knowledge thus appears as realistic. This is an extremely brave outlook for science and for mankind.

26. The validity of the CP in the metagalaxy has yet to be thoroughly examined. What should we conclude if cosmic evolution and deviations from large-scale homogeneity were eventually to be established? In this case, the outlook for cosmology would be poor. Even if science and technology were developed to the limit, our civilization could never obtain information about outside worlds, which would be analogous to the local system, part of which we now observe as the metagalaxy. Cosmology would be reduced from the study of the infinite whole to an "extended geography", to a study of one particular system in a particular phase of evolution. And, as Engels put it (1972): "fundamentally, we can know only the infinite."

27. Fortunately, the latter alternative appears not to be true and the metagalaxy probably affords us a clear window on infinite nature, offering unequivocal cosmic conditions for the becoming of knowledge. The validity of the CP in the observed universe has some important implications for the strategy and methodology of cosmological research.

Thus far, cosmologists have strained to peer deeper and deeper into space in order to obtain relevant cosmological data. If the CP is valid, equally relevant but more reliable cosmological data can be gathered from nearby objects. Every local environment is cosmological. The proverb, "it would be vain to cross the sea in order to catch fish", holds in cosmology as well.

This new state of affairs removes the scientific motive for big science in astronomy and cosmology. It is instructive to note that Hubble achieved a fair sample in his galaxy counts 60 years ago with his 2.5 meter telescope observations extending only to objects 10,000 times brighter and 100 times closer than those observable today. One after the other, later counts to ever fainter magnitudes, and space technology equipped with new spectral passbandsm, have yielded exactly the same qualitative result as Hubble.

The lesson to be drawn is that, while the thrust toward deep-sky observation should not be halted, the emphasis should now be shifted from powerful technology to the more qualitative aspects of the scientific enterprise. In view of advances already made on the empirical front, this appears as the most sensible methodology to follow. Attention to qualitative aspects might entail a more critical attitude to existing theories, analysis of their foundations, systematization of the available data and, subsequently, filling in any remaining holes, developing better analyses and encouraging constant feedback from observation to theory and *vice versa*.

28. From the above philosophical considerations and the cosmological data to be discussed below, a paradox emerges: everything changes, yet the whole does not change. On the philosophical level, the paradox was solved 2500 years ago by Anaximander's statement, so vibrant with dialectical insight (Volkov 1974): "The infinite... is different". In the natural sciences, however, a solution is not yet forthcoming. This is a task for the coming decades and the next century. The general content of this enormous task will be outlined in section V.

IV. Observations

29. The content of the CP, and hence also the empirical discussion, can be divided into spatial and temporal parts. On the former, there is widespread consensus, with the exception of the hierarchical approach to cosmology (de Vaucouleurs 1970, Pecker 1988). The questions of interstellar and possibly intergalactic extinction have apparently not yet been resolved satisfactorily. On the basis of the general body of data we can tentatively infer that structural hierarchy ends at the level of second-order clusters of galaxies. The exact isotropy of the 3ºK and X-ray backgrounds, with fluctuations of only < 0.1 and < 1.3 percent, respectively, indicates that we have indeed reached a cosmological distribution of matter. As yet there is no certainty as to the effective distance to the origin of the X-ray background, while in the quasistatic model the microwave source is set at $z < 1$ (Jaakkola 1982a).

30. The question whether the universe is evolving or unchanging is the most fundamental issue in cosmology. It can be divided into two parts: whether the metagalaxy is expanding or not, and whether or not there are evolutionary effects in discrete objects and diffuse matter over cosmological distances.

Four main groups of tests of the expansion hypothesis can be distinguished. Since these have been reviewed elsewhere (Jaakkola 1983. 1988), here I shall cite only the principal conclusions. First, analysis of the redshift effect in systems of various scales indicates that redshift is stronger within systems than between them (Jaakkola 1977). This contradicts the Doppler interpretation and points to an interaction mechanism for redshift.

Second, the classical global and local test results indicate (Jaakkola, Moles and Vigier 1979) extremely serious internal inconsistencies within the standard theory: the Hubble diagrams always give a closed model, while local tests point to an open one; optical (q,z) tests imply a positive cosmological constant, while the radio (q,z) diagrams contradict the whole range of relativistic predictions. On the other hand, these results, as well as the number counts, agree with the predictions of a non-expanding CP-based model.

Third, the powerful Hubble-Tolman test of redshift and surface brightness data for galaxies, clusters of galaxies, QSO host galaxies and extended radio sources supports the non-expanding model in all four cases (Jaakkola 1986).

The fourth group of tests of expansion concerns the other aspect of the steady-state cosmology, as follows.

31. The question whether the content of the observed universe evolves in time goes to the very roots of the CP and the theory outlined in Section V. In the literature, we find claims of cosmic evolution for parameters such as the spatial density of optically selected quasars (Green and Schmidt 1978, Schmidt and Green 1983), radio (Longair and Sunyaev 1977) and x-ray sources (Giacconi 1980), as well as colour (Butcher and Oemler 1978) and $l_0$4000 break amplitude (Spinrad 1980) of elliptical galaxies. However, on closer inspection it can be seen that the first of these results is affected by a

morphological selection effect (Jaakkola 1982b), the second by an analogous effect and by the fact that the sources fall into two luminosity classes, and this also leads to the third result (Jaakkola 1988b). The fourth and fifth results are probably artifacts of insufficient attention to effects arising from the observational K-term (Laurikainen and Jaakkola 1985). Hence even the "compelling evidence" of cosmic evolution is a false scent.

On the other hand, there are numerous parameters whose constancy over cosmic distances has hardly ever been doubted, while if the CP is not valid, every parameter must be subject to evolution. These parameters include the structural parameters of clusters (Zwicky 1957), as well as flux-related numbers of galaxies (Karachentsev and Kopylov 1977) and the x-ray sources as a single class (Jaakkola 1988b).

32. Therefore, the CP seems to be reasonably well established empirically in both its temporal and spatial dimensions. Of course, this conclusion should be checked for further parameters and with more accurate and more extensive data reaching deeper into space. However, with this provision, we may be optimistic about our conclusion that the proper cosmology of the infinite universe has become a feasible objective.

V. A quasistatic model fulfilling the CP?

33. The cosmological principle continues the tradition originated by the great Greek natural philosophers, forgotten during the decline of culture in the Dark Ages, and renewed in the Renaissance by the Copernican revolution. The CP is an integral part of this revolution, and represents its present form. The status of the full content of the CP in science today indicates that the Copernican revolution has yet to be completed. The present generation of scientists faces the

challenge of completing the revolution by confirming the CP in cosmic nature (provided it is there) and making the first attempts to understand it: this modern form of steady-state cosmology we call “quasistatic”, after Einstein’s first attempt to apply General Relativity to the problem of the universe (Einstein 1917).

34. This task can be subdivided into empirical and theoretical parts. On the empirical front, the correlations between redshift and flux, angular diameter, surface brightness, spectra and various structural parameters, as well as number counts for various classes of objects in various spectral bands must be pushed deeper into space and in different directions. All this data must be analyzed with reference to the alternative theoretical frameworks, mainly the standard model and the new quasistatic model.

It follows from the paradigmatic status of Big Bang cosmology today that, as cosmic nature inundates us with evidence of its steady state, most cosmologists are not prepared to see it. As a result, the presentation and analysis of this crucial data must be particularly clear-cut and consistent.

35. The theoretical task is to explain the structureless and non-evolving universe when we know that everything we observe locally is structured and evolving. I shall propose one possible theoretical approach, although it is by no means implied that this is the only avenue one could adopt: the aim is to introduce the profoundly difficult problems that underlie the CP.

36. It is reasonable to begin with a discussion of the redshift effect. The existence of redshift and its main features follow *a priori* from the fundamental principles of quasistatic cosmology (Jaakkola 1983, Jaakkola 1988b). If the energy of the photons did not decrease as they travel through space, energy in the form of radiation would increase continuously, which is in contradiction to the steady-state aspect of the CP. If z were not independent of rest wavelength, the spectrum of

universal radiation energy would change continuously, again violating the CP. In the quasistatic model, a positive lineshift follows directly from the redshift phenomenon as an absorption effect which cancels the other asymmetric effect of emission. In the Doppler interpretation, the asymmetry $z > 0$ does not follow from the theory itself, since it is inherently symmetrical: planetary and galactic rotation and stellar motions produce both positive and negative redshifts. In order to explain the asymmetry, the standard model is forced to adopt an additional *ad hoc* hypothesis, namely the Big Bang. Of course this is hard to reconcile with fundamental theory, which predicts contraction rather than an expansion.

The third property of redshift, the Hubble relation, can be predicted uniquely and in agreement with observation:

$$m = 5\log(1+z) + 2.5\log(1+z) + K(z) + C \tag{1}$$

Here K is an observational effect depending on z and the form of the spectrum, which in turn depends on galaxy type, and C is a constant depending on the Hubble constant and absolute magnitude. The form of the first term on the right follows from the redshift-distance relation in the quasistatic model:

$$r = \ln(1+z)c/H \tag{2}$$

while the second term gives the energy effect of the redshift on magnitude. The nearly equal but opposite deviations of the two terms from linearity makes (1) practically equal to Hubble's linear law:

$$m = 5\log z + K(z) + C \tag{3}$$

There is also a fourth, lesser-known property of redshift: its strength (h) in systems of various scales increases with the density of the system—$h \propto r^{1/2}$ for typical objects (Jaakkola 1977). This is implied qualitatively by the quasistatic model, where redshift is an interaction effect.

Hence, compared to the standard model, in which fundamental theory is at variance with the main properties of redshift, these *a priori* interpretations from the quasistatic model indicate a superior explanatory power.

37. However, a logical consequence is not yet a physical theory. There are many tired-light theories of redshift, which will not all be reviewed here. Several arguments favour an electro-gravitational coupling as the mechanism behind redshift, as suggested by Zwicky six decades ago (Zwicky 1929, 1957). First, in an equilibrium universe, there must be equilibrium between the various physical interactions as well as between various evolutionary effects. Second, the coupling hypothesis solves other fundamental problems in cosmology, such as the gravity paradox, large-scale structure, stability and homogeneity (cf. Jaakkola 1983, 1987 and 1988c). The $(h,\mathbf{r})$ relation is a third argument. Fourth the solar observations of z and light deflection, which are either not predicted or above the Einstein prediction at $r \leq 3\text{-}4\ R_0$ (Pecker 1976), are obviously not due to two different effects (*i.e.* gravitation and something else), but to a single physical effect that indicates a coupling of the gravitational and electromagnetic interactions. The theoretical line of thinking involved in the electro-gravitational coupling hypothesis appears to constitute a plausible link between the fundamental principles of quasistatic cosmology, redshift and the further developments which will be discussed below.

38. Just as is a direct path from the CP to redshift, there is also a direct connection between redshift and the 3ºK background radiation. Redshift implies a decrease in photon energy from E_0 to $E_0/(1+z)$. The absorbed fraction of the energy $E_0 z/(1+z)$, which we shall call redshift energy, cannot gather in space indefinitely, but must be released in some way through a re-emission process. We observe this re-emission

of redshift energy as the microwave background radiation. The fundamental properties of the microwave background follow directly (Jaakkola 1983, 1982a, 1988c).

The luminosity intensity due to discrete sources, weakened by redshift and integrated to infinity, yields a finite value for the theoretical background radiation energy density similar to the observed energy density of the microwave background. Its temperature can be predicted from the tired-light relation (Pecker 1976):

$$h = cAT^3 \tag{4}$$

where the constant A is obtained from local observations and h is now equal to the Hubble constant H. Strong limits ($1\text{ K} \leq T \leq 5\text{ K}$) are obtained, with the observed value somewhere between. A slight deviation of the observed spectrum from the blackbody curve is qualitatively similar to an expected redshift distortion of the re-emission spectrum. A correct value can also be obtained for the dipole anisotropy without the hypothesis of local motion valid for an unrealistically large portion of the metagalaxy. The similar energy densities of the microwave background and local galactic starlight follows directly from the interpretation of large-scale structure (Jaakkola 1983, 1987). The question of the cosmic photon-baryon number ratio is thus reduced to the astrophysical problem of the ratio of the emissivity of matter to redshift re-emission.

39. One cosmological detail deserves further scrutiny: the quasar problem. While the energy of the cosmological redshift from galaxies and part of the quasars is released as redshift re-emission in the form of the microwave background, the energy of the intrinsic redshift in another group of quasars is re-emitted as redshift radiation around the central source, constituting a fraction of the total luminosity of the QSO which increases with z as $z/(1+z)$. This is seen as correlations of

redshift with magnitude, continuum spectrum, line-continuum ratio, variability, *etc.* As a new theoretical framework within which general QSO data can be interpreted, this view holds out great hope for progress in the quasar problem (Jaakkola 1984). The redshift re-emission forms the connecting link between the most diffuse and the most condensed forms of radiation.

40. One theoretical task in quasistatic cosmology and in concrete work on the CP is to develop theoretical predictions for the global cosmological relations applicable to empirical tests. The (m,z) relation was given in equations (1) and (3), while angular diameter (q) is related to redshift as follows (with D the linear diameter):

$$q = Dc/H\ln(1+z) \tag{5}$$

Surface brightness (SB) diminishes with increasing z as:

$$\mathrm{SB}(z) = \mathrm{SB}(0)/(1+z) \tag{6}$$

while in the standard cosmology, SB varies as $(1+z)^{-4}$. The pronounced difference makes this test a powerful tool in cosmology. For the number-magnitude and number-flux relations, one obtains, taking into account that $N \propto r^3$, $S \propto r^{-2}(1+z)^{-1}$ and $m = -2.5\log S$, the relations

$$\begin{aligned} 0.6m &= \log N + A_1 N^{1/3} + C_1, \\ -1.5\log S &= \log N + A_2 N^{1/3} + C_2. \end{aligned} \tag{7}$$

The second terms on the right side of equations (7) become important only in very deep counts.

As noted in section IV, the data are in agreement with the predictions of the quasistatic model for global relations (Jaakkola 1983, Jaakkola, Moles, Vigier 1979, Jaakkola 1986, Jaakkola 1988a).

41. In a universe that is consistent with the CP, the equation

$$p(z) = \text{constant} \tag{8}$$

must be valid in the statistical sense for any absolute spectral or structural parameter *p*. Applied to various parameters, classes of objects and spectral bands, equation (8) points to dozens of different possible tests of the CP and the quasistatic model.

42. The above global considerations attached to relations of redshift or flux with other parameters can be referred to as a "vertical cosmology". The study of the properties of matter at fixed distances, which would then be a "horizontal cosmology", can yield information on matter content (*e.g.* the luminosity function) and on evolutionary processes. On the other hand, if the evolution of a particular class of objects can be dealt with theoretically, the theoretical time-scales and observed frequencies can be compared. This gives rise to a new class of tests capable of distinguishing between the quasistatic and standard models.

Young objects at small distances and old objects at large *z* are most informative. Note that the wide dispersion of evolutionary states, which is very obvious, for example in X-ray data for clusters of galaxies (Giacconi 1980, Jaakkola 1988b), is predicted by the quasistatic model but can only be accommodated by the standard model through *ad hoc* assumptions.

43. From the foregoing paragraphs and from Section IV, we can conclude that the CP and the quasistatic model, with its unambiguous predictions and no free parameters (arising from evolution, expansion rate or geometry) can be confirmed or falsified with a fairly high degree of certainty.

44. The final problems underlying the CP may now be addressed. The first paradox is: everything in the universe is structured, but the whole is not. The second paradox is: everything around us is evolving, but the whole does not evolve.

The task in the former case is to explain the local hierarchical structure and its transformation into a uniform cosmological distribution. The question has been examined elsewhere (Jaakkola 1987); here it will be sufficient to give the solution in general outline. The electro-gravitational coupling weakens both photon energy and gravitation at the same time and with the same rate, by an exponential factor:

$$\exp(-Hr/c)$$

This gives the "Machian" gravitational interaction of cosmic masses a finite value of $a_c = 4\mathbf{p}Gc\mathbf{r}/H \sim 6.4 \times 10^{-9}$ cm s^{-2}. The gravity paradox is thus solved. The gravitational acceleration due to discrete systems at their edges (a_s) appears to be similar to or slightly larger than a_c, indicating that the Machian interaction controls the formation of structure at the hierarchical levels of galaxies and first and second order systems of galaxies. The equation

$$a_s \geq a_c \qquad (9)$$

is thus one of the basic laws characterizing the quasistatic universe, which expresses the dialectical relation between the infinite and the local in the cosmos.

For supergalaxies, we already have $a_s \leq a_c$, and therefore these and the elongated chains into which they evolve (probable due to Machian pull) can be expected to represent the largest individual structures in the universe, which must also be distributed uniformly in space. This prediction fits available data. Because any larger concentrations cannot form, this relation also explains cosmological stability.

If the solution suggested here is confirmed, then a theoretical link can be said to exist between major features of the universe (redshift, microwave background, solutions of Olber's paradox and the gravity paradox, galaxies and their systems, homogeneity and isotropy, stability. Further elaboration and empirical confirmation of this theoretical chain connecting the grand features of the universe would mean an important step in our understanding of nature.

45. The temporal aspect of the CP is the most formidable challenge of the quasistatic model, and the answer to it will form the essence of any ensuing physical theory. While the properties of matter obviously change locally, we must find other processes that keep these properties invariant on the large scale (Jaakkola 1983). We need to find the keys to the cellar of the house of matter.

We can identify various processes, some of which increase local density, and some of which decrease it, giving rise to an equilibrium density distribution. The processes in which encounters between members of a stellar or galactic system play a decisive role, leading to a net inward motion in the inner region and an outward motion in the outward region of the system have been extensively studied. The explosive motions originating in the nuclei of galaxies, the tidal pull from neighbouring galaxies and the Machian force of distant masses are other components of the process that maintains density in equilibrium. Accretion of newly created baryonic matter into existing and new galaxies must also be taken into account. The formulation of an explicit theory of the density equilibrium of matter is a task for future research.

46. Tidal friction due to halos and neighbouring galaxies tends to decrease the angular momentum of disks of galaxies. We must find the effects which allow the rapid rotation of spiral galaxies in spite of the infinite duration of this kind of braking. A partial explanation may come from the eruptive mass outflows from galactic nuclei, which triggers a wave of outward motions of stars which have a peculiar motion in the direction of rotation. This would increase rotational kinetic energy at the expense of energy in random motions. It is germane here to point out the general correlation of the rotational and other activity.

However, this does not explain the close similarity of a_c and a_s, the latter involving rotational energy. The accretion of newly formed baryonic matter, controlled by the equilibrium of the local and global gravitational forces, probably plays a role here. Accretion increases rotation, just as water poured down a sinkhole creates a vortex.

47. In the emission processes in stars, galactic nuclei and radio sources we see matter change form from particles to electromagnetic radiation. A reverse of this process must also be taking place. The facts underlying Olbers' paradox provide a clue to the problem of photon-baryon equilibrium.

In the quasistatic model, Olbers' paradox can be solved as follows:

When part of the redshift energy is re-emitted as microwave background, the rest is consumed in particle production. The rate of production is (Jaakkola 1988a in press)

$$C_m = L/c^2 \tag{10}$$

where L is luminosity density. The numerical value of C_m is $\approx 3 \times 10^{-53}$ gs^{-1} cm$^{-3} \approx 1$ galaxy per Mpc^3 per 10^{16} years which is 5×10^{-4} times the value in the steady-state model and, remarkably, corresponds to the energy density of the high energy cosmic ray particles which are of extragalactic origin. Within galaxies and particularly in quasars with intrinsic z the creation rate is higher, but due to the larger volume the total amount of production in intergalactic space is greater.

An explicit physical theory of the photon-baryon equilibrium, required by the general cosmological facts, may be a key ingredient of particle physics in the not so distant future.

48. If hydrogen burns into helium and heavier elements in stellar nuclear processes, another process must be found which maintains the equilibrium of element abundances. Qualitatively, replenishment of hydrogen is not a problem, since all nuclear processes yield radiation

which will be transformed into hydrogen, as just discussed. The dissolution of elements heavier than iron happens spontaneously. The main problem then, is how to dissolve iron, which is a very stable element. In the extreme temperatures of supernovae iron can break up into helium and hydrogen nuclei (Sklovskii 1978). A similar process might also be occurring in the "smelting furnaces" of galactic nuclei.

Empirically, it is interesting that hydrogen, helium and iron, all of which are produced in both fusion and fission processes (for "fusion" of H, see paragraph 47 above), and all of which are stable nuclei, are at the same time the most abundant elements. The equilibrium distribution of element abundances was noticed as early as 1917 (Harkins 1917). Recent observations of an unexpected constancy of iron in galactic stars of various ages and distances from the galactic plane (WSAGE 1988) point to the existence of an equilibrium process, as does the correlation between metallicity and luminosity of elliptical galaxies. In the quasistatic model, dwarfs with low metal content are younger objects than the giant galaxies of which they are satellites.

49. Because the spiral arms are wound up by differential rotation (we will not adopt the perpetual arm hypothesis of the density-wave theory here), and the aggregates of stars and interstellar matter are gradually smoothed down, there must also be opposite processes that set up these structural features. An equilibrium process is also needed to replenish star populations.

The main candidates for the mechanism behind spiral structure are instability of the disks, tidal forces due to encounters with other galaxies and explosive outflows from galactic nuclei. The third effect was first examined by Ambartsumian (1958) and Arp (1969), and it has been verified empirically in numerous galaxies, including our own. It has the virtue over other models that it not only appears in the numerical simulations, but nuclear activity has an important role in all

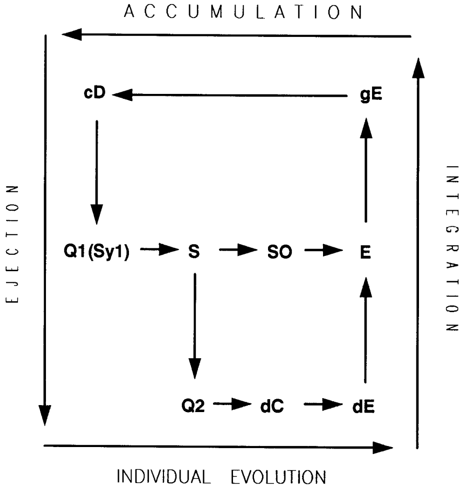

Figure 1 - Evolutionary scheme for galaxies. Q1 and Q2 are two classes of quasars. Q1 is thought to be identical with Seyfert galaxies, while Q2 consists of local quasars with intrinsic z. Key: d-dwarf, g-giant.

equilibrium processes discussed above. It is a unifying factor in the quasistatic model, the local factor having a role opposite to the Machian force of the infinite background.

An interconnection of local and global factors in the equilibrium processes is characteristic of the approach suggested here. Cosmology is seen as the science of the unity of the infinite and the local, and the unity of the other opposites that abound in nature.

50. Galactic evolution is intimately connected to the extragalactic environment. Galaxies belong to groups, clusters and larger systems, and around the major galaxies are dwarf galaxies, local quasars and globular clusters as satellites. Galaxies originate mainly by the activity of the nuclei of the larger galaxies. They evolve according to internal dynamics and in interaction with the surrounding galaxies, diffuse matter and the whole larger system, as well as with the rest of

the universe. Periods of smooth evolution are punctuated by violent phases (cosmological QSOs, Seyfert galaxies and other AGNs) and phases of quasi-stationary and abrupt evolution may be repeated several times in the history of a galaxy. Galaxies die by losing their identity and merging into the major galaxies or forming supermassive galaxies in the centre of clusters. The eternal cosmic cycle of matter continues from there.

Figure 1 is a schematic representation of the origin, evolution and fate of galaxies, as proposed by the quasistatic model. This schema of evolution and relationships between galaxies (the "extended Hubble sequence") (Jaakkola 1983) does not cover all forms of evolution, and may be inaccurate in some details. However, it does encompass the main categories of morphological change (fragmentation, individual evolution, merging and accretion), offering a good illustration of the complexity of the problem and at the same time the basic idea of the quasistatic equilibrium model.

51. In this article we have discussed problems that lead directly to fundamental physics. Therefore, the paradigmatization of the CP in cosmology will also entail a thorough reconstruction of physical theory.

The coupling of electricity and gravitation, which is the cause of the redshift and the exponential weakening of gravitation, does not invalidate Newton's theory: it only makes it inapplicable on the cosmological scale, on the scale of galaxies and their systems, and probably in many cases also on smaller scales. The gravitational parameter G changes from a constant to a physical variable which is constant only over the homogeneous distribution on the cosmological scale.

Coupling of the two long-range physical interactions and, empirically, solar and cosmological observations, calls Einstein's theory of gravitation into question. On the methodological level, this theory can be criticized for its geometrization of physics, which must ultimately be a doctrine of interactions of matter.

The principles of equilibrium of element abundances and constancy of the photon-baryon number ratio will, when confirmed directly or indirectly by observations, bring about profound changes in nuclear physics and quantum theory. The extremely speculative application of quantum theory to cosmology, namely the hypothesis that the Universe is a quantum fluctuation of the vacuum, can be totally forgotten.

The CP and quasistatic cosmology do not violate the theory of thermodynamics; rather, they set the limits of its application. These are the same as the limits of the hierarchical organization and local evolution of matter.

The theory based on the CP also implies a thorough change in our concepts of space and time (Jaakkola 1980). If electro-gravitational coupling is confirmed, the special and general theories of relativity become untenable, since it would be absurd to equate one kind of motion in space and time (*i.e.* the deflection and dilation of photons) with the absolute character of space and time. Instead, an effort can be made to rationalize the Newtonian concepts of absolute space and time: of course these will have physical foundations which must be formulated mathematically.

One implication of the CP is that there is no cosmic time. In a sense, when the arrow of time approaches infinity, it ceases its flight.

The cosmological facts underlying the CP guide our attempts to achieve a unified physical theory and provide a realistic basis for unification. For example, the redshift implies a connection between gravitation and electromagnetism; the photon-baryon equilibrium implies a connection between the electromagnetic and nuclear interactions.

52. Consequently, the task of establishing a cosmology based on the Copernican cosmological principle requires both observational and experimental work, as well as theoretical work in the fields of cosmology, astronomy and general physics. But this cannot be achieved without philosophical work in clarifying concepts, sharpening methods and pointing out the basic ontological content of the cosmological problem. In particular, the materialist ontological statement which is the focus of the temporal aspect of the cosmological principle, namely that matter is indestructible not only in the quantitative sense, but also in the qualitative sense, cannot be avoided in cosmology. To cite the poignant analogy used by Engels (1972), we cannot pass it on by renewing the bill of exchange and vanishing.

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