## COSMOLOGY AND MAGIC*

Cosmology, one of the oldest disciplines—and perhaps the least disciplined of all—provides the core of our world-view. It must be recalled, however, that there is not a single cosmology, just as there is not a single world-view. Nowadays there are, in fact, three main kinds of cosmology: scientific cosmology (a business of astrophysicists), science-fiction cosmology (the hobby of some astrophysicists), and philosophical cosmology (the concern of some scholars interested in ancient opinions about the cosmos).

Scientific cosmology is a branch of physics: it is nothing but megaphysics, i.e., the physics of huge quantities of matter and volumes of spacetime, a discipline built on the basis of both macrophysics and microphysics. Science-fiction cosmology weaves a colorful and fantastic tapestry to represent the world as a whole, with threads of physical knowledge and threads of unchecked fantasy. Finally, philosophical cosmology is both more speculative and less creative and stimulating than science-fiction cosmology: it draws on obsolete physics (mainly Aristotle's), and its function is apologetic rather than cognitive or entertaining.

Scientific cosmology is barely born and philosophical cosmology is nearly dead; only science-fiction cosmology is fully flourishing, both in popularization books and in scientific journals. It has pep and imagination-appeal, it is literarily well-presented and generously advertised. There are few more effective traps for catching the last of the innocent:

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the philosopher. The present paper will attempt to describe and analyze one of these attractive pitfalls: the steady-state theory of the universe, sometimes modestly called "the New Cosmology".

## *1. Some Cosmological Models*

The way cosmologists work is typical of modern science: a hypothetical model is first contrived to cope with a few characteristic (but uncertain) data, and its consequences are worked out and finally contrasted with a vast number of largely hazy observational data recorded in tables, empirical curves, photographs, photometric curves, and so on. The difference between the scientific and the semiscientific cosmologist does not lie in the amount of imagination spent in building the hypothetical model of the cosmos, but in the materials used to construct the model, and in its test: the model may or may not be based on accepted physical laws, and it may or may not be testable and satisfactorily tested for the time being. In particular, science-fiction cosmologies will tend to use ideas of archaic supernaturalistic cosmogonies (notably the creation concept), and will either tend to elude test or conflict with evidence.

A variety of models of the universe have been imagined since, in 1917, Einstein inaugurated the contemporary stage of cosmology. Some models are spatially infinite, others have a finite volume; some have a beginning in time, others are eternal; some are static, others expanding, and others are cyclical (successively expanding and contracting). Finally, the steady-state theory,[1] which will concern us,

[1] A masterly account of this theory will be found in H. Bondi, *Cosmology*, 2nd ed. (Cambridge: University Press, 1960). The inaugural paper was by H. Bondi and T. Gold, *Mon. Not. R. Astr. Soc.*, **108**, 252 (1948). Able popularizations of the same theory are to be found in H. Bondi, *The Universe at Large* (New York: Anchor Books, Doubleday & Co., 1960), F. Hoyle, *The Nature of*

postulates a model which is infinite in both space and time, and which is neither static nor evolving as a whole: it is stationary, in the same way as an organism maintains a steady-state by replacing its outworn parts.

According to the latter picture, the universe was not created some time ago but is continually being created out of nothing: fresh matter is continually added to the aging stars, so that the sum-total is neither young nor old. There is no increase in density owing to the continual creation of matter, because the universe is expanding as a whole. Consequently, this expanding but replenished cosmos should look much the same in all places (homogeneity), in all directions (isotropy), and at all times (non-evolution).

We shall go into details of the steady-state theory later. For the time being suffice it to say that the models involving creation out of nothing, either spontaneously or by Somebody, and whether of the universe as a whole (initial "big bang") or of single particles in a continual form, violate basic conservation laws entrenched in physics, as well as the ontological principle according to which nothing comes out of nothing or goes into nothing (the genetic principle, or postulate of non-magic). Considerations such as these are all-important in the present stage of cosmology owing to the scarcity and imprecision of observational data. Given the indirect and often ambiguous nature of the empirical evidence relevant to cosmological theories, the cosmologist exposes himself, perhaps more than any other, to philosophical criticism—not to mention ideological indictment.

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*the Universe,* 2nd ed. (New York: Harper, 1960), and H. Bondi, W. B. Bonnor, R. A. Lyttleton, and G. J. Whitrow, *Rival Theories of Cosmology* (London: Oxford University Press, 1960).

## 2. *The Steady-State Theory*

The steady-state model of the universe is built with assumptions and results of the steady-state theory. (Usually a theory is consistent with a number of models or pictures of its object: witness the compatibility of various cosmological models with the relativistic theory of the gravitational field. The reasons for the general lack of one-one correspondence among theories and models are: *(a)* not every statement of a theory need or can be employed in building a model: e.g., the differential equations that usually belong to a physical theory cannot be thus employed because only their solutions are descriptive of events; *(b)* the model may involve specific assumptions and empirical data not contained in the general theory. But this point need not detain us here because the steady-state theory, in contrast with relativistic cosmology, involves a single model.)

The steady-state theory can be regarded as a solution of a contradiction between the appearance of uniformity (large-scale uniformity of the distribution of matter), and the continual mutual recession of the nebulae (galaxies other than our own, the Milky Way). In other words, the theory solves the following legitimate problem: Find how the over-all aspect of the universe is kept (approximately) unchanging, while the galaxies recede from one another. So far, so good, since the starting point of the theory is a genuine scientific problem, consisting in the incompatibility of two hypotheses that are widely held—but which should not be regarded as immutable.

The theory effects the conciliation of two assumptions which it does not question: the hypothesis of uniformity in space and time (the so-called "Perfect Cosmological Principle"), and the hypothesis of expansion. The conciliation is brought about by adding a third assumption; in fact, the hypothesis of the continual replenishment of matter is added as a *tertium quid* in order to remove what would otherwise be a contradiction between the cosmological principle and the expansion hypothesis. If either of the two initial assumptions (homogeneity and expansion) is dropped, or even modified, the whole point of the theory disappears. In other words, the steady-state theory is extremely rigid: it cannot grow in steps of successive improved approximations.

Before examining the proposed solution in greater detail we must take a further look at the problem which generated the theory: the value of the solution would not, after all, be very high if the initial problem itself were actually less dramatic than it appears to be. The "perfect cosmological principle", which the steady-state theory postulates, can be stated thus: The universe presents the same aspect from every point and at every instant, except for local irregularities. This was a very natural (i.e., likely) assumption to make before the recent radioastronomical data reported on in section 7, because observation showed no systematic variations of density and no systematic arrangement of celestial objects according to age. And also because, from a methodological point of view, it is a simplification that facilitates the start of theorizing. There is nothing wrong with trying a simple hypothesis; what is wrong is to regard it as definitive.

The expansion hypothesis—the second main foot of the steady-state theory—is likewise founded on available observation—that is, on the kind of indirect observation presupposing theory, which characterizes astronomy as much as it does atomic physics. What can be "seen" is (*a*) that the galaxies are unequally bright, and (*b*) that the fainter a galaxy the more its spectral lines (the optical identification cards of the various elements occurring in the stars) are shifted to the red, relatively to the spectrum of the same elements as observed in the laboratory. These facts can consistently be interpreted by means of the following hypotheses: *(a)* the fainter a galaxy the more distant it is—at least on the average; *(b)* the red-shift of the nebular spectra is an indicator that the nebulae are in recession motion. The first hypothesis may confidently be regarded to obtain on the average as tested whenever the distances are estimated independently from brightness. The second hypothesis (i.e., that the reddening of light is a Doppler-Fizeau effect) is at present the most plausible, but by no means the sole possible explanation. Alternative hypotheses might be consistent with the same evidence, such as the "aging" of light as a consequence of its interaction with the gravitational field or with the interstellar matter—or even with the interstellar "vacuum", to which quantum electrodynamics assigns so many physical properties.[2]

Although the interpretation of the nebular red-shift as a Doppler-Fizeau effect—hence as a symptom of the mutual recession of the galaxies—is by no means final, it is certainly the most likely at the moment. If accepted for the observed part of the universe, it provides a means for calculating the velocity and even the acceleration of recession. On this basis, it is concluded that all the observed galaxies are moving away from one another—whence the ex-

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[2] This last possibility does not seem to have been explored, yet it is interesting. The galactic electromagnetic fields would polarize the "vacuum", or space, in analogy with the polarization of dielectrics: virtual electron pairs would be produced. An incoming photon could be absorbed by one of the virtual electrons, which would subsequently unite itself with the other electron, as a result of which they would "annihilate" with emission of a photon with slightly different frequency. But the simple classical scattering of light by galactic electromagnetic fields, as suggested by nonlinear electromagnetic theories like Born's, would produce the same effect. See E. Finlay-Freundlich, *Proc. Phys. Soc.*, **A, 67**, 192 (1954).

plored portion of the universe is, at least at present, expanding. (In section 7 we shall see that recent data suggest a slowing down of the expansion.)

Yet it might well occur that other, still unknown parts, are in a process of contraction; and it may also be that the present expanding stage be followed by a contracting phase, as claimed by the relativistic cyclical models.[3] The data at hand endorse a limited expansion hypothesis; they do not ensure the universal hypothesis of indefinite expansion of both the explored and the unexplored parts of the universe. In addition, the hypothetical expansion still remains unexplained: nothing is known about either a cosmic explosion in the distant past, or a long-range repulsive force that overcomes gravitational attraction. And modern science feels ill at ease with unexplained facts—especially if imperfectly established.

Be it as it may, *if* the universe is expanding, then its density will decrease—unless new matter is continually added to it. And this is what the steady-state theory postulates: "As ageing nebulae drift apart, due to the general motion of expansion, new nebulae are formed in the intergalactic spaces by condensation of newly created matter. Nebulae of all ages hence exist with a certain frequency distribution".[4] The prospect of continual rejuvenation is certainly attractive; unfortunately, (*a*) no plausible theories of either the creation of matter or the condensation of newly created matter are offered by the steady-state theoreticians; and (*b*) observational evidence in favor of the contemporary synthesis of atoms and galaxies, if available, would not support the steady-state theory unambiguously,

[3] R. C. Tolman, *Relativity, Thermodynamics, and Cosmology* (Oxford: Clarendon Press, 1934), and *Revs. Mod. Phys.*, **21**, 374 (1949).

[4] H. Bondi, *Cosmology*, p. 140.

because it could be accounted for by theories not postulating the creation of matter *ex nihilo*.

In short, the steady-state theory does solve a riddle, but (*a*) the postulated spacetime uniformity and expansion are far from being established; and (*b*) to solve a riddle by inventing a mystery is at least puzzling. Let us approach the mystery more closely.

## 3. *The Main Hypotheses of the Steady-State Theory*

To facilitate analysis let us begin by listing the chief assumptions of the theory.

(i) The universe is spatially infinite.

(ii) The universe has neither a beginning nor an end in time.

(iii) Except for local irregularities, the universe is everywhere much the same. (As a consequence, for purposes of certain calculations all the matter in the universe can be regarded as smeared out uniformly.) This is the restricted cosmological principle, shared by most cosmological theories.

(iv) The universe is always much the same: there is local evolution and involution, but no over-all change. This postulate, conjoined with the preceding one, constitutes the "perfect cosmological principle".

(v) The universe expands with constant positive acceleration. (More exactly, the scale factor is $R(t) = \exp(2t/T)$, where 'T', the reciprocal of Hubble's constant, is about $10^{10}$ years.)

(vi) Matter is continually being created out of nothing at a rate which exactly compensates for the decrease in density produced by the uniform expansion. (More exactly, the average creation rate is one hydrogen atom per litre per about $5 \times 10^{11}$ years.)

The first hypothesis, regarding the infinity of the universe, is at present as much of a dogma as the hypothesis of the spatial finitude of the universe: both hypotheses are equally ungrounded at the present time. Moreover, further observation might be insufficient to make a decision among the two, for every extension of the reach of telescopes and radiotelescopes could be interpreted as a correction on previously calculated radii of the universe; and even the lack of visible objects beyond a certain radius might be interpreted either as a confirmation of the hypothesis of finitude, or as either a huge void shell or a shell filled with absorbing dust, both in an infinite universe. Only theories which, like general relativity, assert a relationship between the density of matter and the curvature of spacetime, allow for a decision of this question with the help of observational data regarding the distribution of matter and the paths of light rays. But available data are insufficient, and the steady-state theory either does not accept general relativity or is not altogether consistent with it, if only because relativistic physics involves the conservation of matter.

The second hypothesis ("The universe is temporally infinite") is required by any this-worldly *Weltanschauung* and any scientific cosmology; it is, moreover, required by the principle of non-magic (see section 1 above). Yet, there is a difficulty that should be met: many independent inquiries converge to a so-called "time-scale" of about ten billion years; this time scale is obtained by the study of rocks, meteorites, stellar evolution, and other fields. Creationist cosmologies interpret this time as the age of the universe. Noncreationists, on the other hand, interpret the time-scale as either the maximum age of the known galaxies, or as the beginning of the present phase of expansion, or as some presently unknown cosmic cataclysm which ended a previous stage of the eternal universe and marked a fresh start of its history.[5] At any rate, some reasonable interpretation of that number must be given—which the steady-state theory does not. In short, the second hypothesis, which is basically sound, ought to be supplemented with some grounded hypothesis explaining the time-scale.

The third hypothesis, stating the homogeneity and isotropy of the universe, is to a first approximation consistent with the data at hand. But it is quite frail because it is not a physical law but, rather, a statement concerning a mass distribution that, after all, might have been different. One and the same set of laws is consistent with an infinity of different distributions, provided the distributions at an earlier time differ, too. In other words, the cosmological principle should not be regarded as a law but rather as an initial condition. Moreover, as already hinted, recent observation challenges the exact validity of the restricted cosmological principle (see section 7).

The fourth hypothesis, asserting the temporal over-all uniformity, sounds reasonable and has been put forward by other cosmologists in the past, such as Arrhenius and Vorontzoff-Velyaminov. Yet it would be unwise to regard it as established. Consequently a well-built cosmological theory should make room for modifications of this, which is essentially a simplifying hypothesis, instead of regarding it as incorrigible.

The fifth hypothesis, concerning the expansion of the universe, is reasonable if applied to the hitherto scanned part of the world and to the present epoch, but becomes

[5] Cf. M. Bunge, *La edad del universo* (La Paz: Laboratorio de Física Cósmica, 1955), and W. B. Bonnor, reference 1, pp. 6 and 53.

highly controvertible if extrapolated beyond this. Moreover, the precise constant rate of expansion assumed by the steady-state theory seems to be contradicted by recent observation (see section 7).

The sixth hypothesis—concerning the continual popping up of matter out of nothing—is not, like the previous assumptions, a regular member of scientific knowledge: it is no less scandalous a fiction than the conjecture that the universe was created with a stroke a few billion of years ago. Either creation hypothesis smuggles magic into cosmology, thus turning it into science-fiction. This contention will be argued in the next section.

Of the six main hypotheses that characterize the steady-state theory, then, only one ("The universe is eternal") is unobjectionable on either scientific or philosophic grounds; but it needs supplementation to account for the "time-scale", and its merit is ruined by the continual creation hypothesis. Three further hypotheses of the theory (spatial homogeneity, temporal uniformity, and expansion) are plausible if certain qualifications are appended, but are by no means certain; moreover, the precise form of the expansion hypothesis adopted by the steady-state theory is inconsistent with available data. Another hypothesis (stating spatial infinity) is as likely as its opposite. Finally the hypothesis of continual creation, which is peculiar to the theory under examination, is indefensible.

A sober verdict would, then, seem to be this: The steady-state theory is partially true. Unfortunately, (*a*) the plausible hypotheses of the theory are not its exclusive property, so that empirical evidence consistent with them does not support the theory unambiguously; and (*b*) the theory cannot be perfected by adjusting its distinctive postulates, the temporal over-all uniformity and the continual creation of matter: either the universe is or is not selfidentical in time, and matter is either created or uncreated. This incapacity for self-correction and growth takes the theory dangerously close to dogma.

### 4. *The "Law" of Creation of Matter*

That matter can be transformed, but not created out of nothing, has been maintained by scientists since Lavoisier established his law of mass conservation (later slightly corrected). The hypothesis was further supported by the "discoveries" of the law of conservation of energy (Mayer, Joule, Helmholtz, and others), and the theorem of conservation of electric charge (Maxwell). True, when an electron and a positron (or a proton and an antiproton) are formed out of radiation, one speaks of "pair creation"; likewise, the transformation of an electron (or proton) pair into a photon is usually called "pair annihilation." But it is clear that both 'creation' and 'annihilation' are here misnomers, since transformations and not magic appearances and disappearances are at stake.

In all known transformations several quantities remain constant, provided the changes occur in a closed system. Some of the most important constants of transformation are the total energy, the total electric charge, and the difference between the total number of fermions (half-spin particles) and the total number of antifermions. On the other hand, the mass, the linear momentum, the angular momentum, the spin, and the number of bosons (integral spin quanta) do not remain constant in all transformations; they vary, in particular, whenever light or heat are absorbed or generated.

(Strictly speaking, there is no law of conservation of matter, but rather a set of conservation laws referring each to some property of particles and fields. These laws are not mere conventions, but are testable axioms or theorems of definite physical theories. Macrophysics sums up the conservation of matter, at the level of matter in bulk, in the law of the total energy-momentum-stress conservation, $\frac{\partial T^{\mu\nu}}{\partial x^{\nu}} = 0$. This, a macrolaw, is rigorously deduced from the relevant microphysical conservation laws, which in turn derive from equations of motion. It is anything but a stray assumption.)

Until fifteen years ago nobody in the scientific community dared criticize the law of conservation of matter (i.e., the set of basic conservation laws) ; it was and still is consistent with all known empirical data and theoretical laws—and scientists are not prone to make radical changes unless forced by logic or by experience. But between 1947 and 1949, at least five scientists[6] challenged the law of conservation of matter. This they did on no ground whatsoever and for the exclusive benefit of highly speculative theories. We shall mention two such violations.

The "law" originally proposed by Bondi[7] states that the quantity of matter emerging in a closed volume of spacetime is proportional to that volume and independent of place and time. Such a rate of creation would not be determined in accordance with some mechanism: there would be no mechanism, the rate being solely determined by the need to keep a constant density of matter in the

[6] P. Jordan, *Die Herkunft der Sterne* (Stuttgart, 1947), unavailable to the writer; *Nature,* **164,** 637 (1949); F. Hund, *Zeits, f. Phys.,* 124, 742 (1948); H. Bondi and T. Gold, reference 1; F. Hoyle, *Mon. Not. R. Astr. Soc.,* **108,** 372 (1948), and **109,** 365 (1949).

[7] See Bondi, *Cosmology,* p. 149. A mathematical transcription of this "law" is this: $dm/d^4x = 3\rho_0/T$, where '$d^4x$' designates the element of proper space-time volume, '$\rho_0$' the mean density of matter in the universe, and '$T$' the reciprocal of Hubble's constant.

universe—i.e., by the need of saving the "perfect cosmological principle".

A refined version of this "law", proposed recently by Hoyle,[8] is relativistically covariant and does involve a mechanism of sorts: it states that matter radiates a "creation field" which contributes a term to the total energy-momentum-stress tensor occurring in Einstein's gravitational field equations. Curiously enough, the "creation field" does not react back upon its source, so that it cannot be evidenced by studying the motion of the latter, let alone by watching its presumptive absorbers, about which nothing is said. This refined version of the creation "law" is no less a *deus ex machina* introduced to rescue the "perfect cosmological principle", than the coarser formulation. Let us see what is wrong with the "law" in either formulation.

## 5. *The Mathematical, Physical, and Philosophical Implausibility of the Magical Law*

The "law" of creation of matter can be criticized on three counts: mathematically, physically, and philosophically. A mathematical criticism has recently been raised by two distinguished cosmologists,[9] who have shown that the "creation field" introduced by Hoyle[8] is not uniquely determined by the postulated wave equation. This renders the creation energy-momentum-stress tensor arbitrary and the description of the motion of matter indetermined, or at least not uniquely determined. As a consequence, no definite predictions are possible. The critics conclude that "the

[8] F. Hoyle, *Mon. Not. R. Astr. Soc.*, **120**, 256 (1960). The wave equation of the "creation field"$\phi$, as rewritten in the usual notation, would be

$$g^{\mu\nu} \frac{\partial^2 \phi}{\partial x^\mu \partial x^\nu} = 3c^2 \rho.$$

theory [of Hoyle] must be regarded as incomplete."[9] We may add that, since this theory affords no definite predictions, it is empirically untestable. And this, as Karl Popper has taught us,[10] is the grossest insult that can be addressed to a theory purporting to be scientific.

From a physical point of view the following objections must be raised against the "law" of creation of matter. First, there is no way of testing the "law" either in the laboratory or by fairly direct astronomical observation, because (*a*) the creation rate is so slow as to exclude any such tests, and (*b*) no reaction of the "creation field" on real matter is assumed. In other words, the "law" of creation of matter successfully eludes empirical test and must therefore be gauged by criteria other than predictive power. Second, the formulas proposed by Bondi and Hoyle are classical (nonquantal), hence they cannot be expected to account for the details of what, *ex hypothesi,* is a "fundamental" microphysical process. Third, the "law" conflicts with the best established laws of physics; in other words, it fails to pass the test of matching with the bulk of accepted knowledge. In short, the creation of matter conjecture is theoretically unwarranted and empirically ungrounded.

As to a philosophical criticism of the creation fantasy, it might run as follows. The hypothesis conflicts with the whole "spirit" of modern science, which abhors creation *ex nihilo* (magic) and accepts, on the other hand, Lucretius' genetic principle, according to which nothing comes out of nothing or goes into nothing.[11] In assuming that

[9] W. B. Bonnor and G. C. McVittie, *Mon. Not. R. Astr. Soc.,* 122, 381 (1961).

[10] K. R. Popper, *The Logic of Scientific Discovery* (1935; London: Hutchinson, 1959), especially chs. I and IV.

[11] For a discussion of the postulate of non-magic and its relation to the steady-state theory, see my *Causality: The Place of the Causal Principle in Modern Science* (Cambridge, Mass.: Harvard University Press, 1959), pp. 24-25 and 240.

the emergence of matter, though lawful, is determined by nothing (indeterminate),[12] the steady-state theory endorses radical indeterminism—or, to put it bluntly, it endorses magic. Logicians may not be impressed by an ontological argument such as this, or even by the previous criticisms of a mathematical and physical character; but they ought to be persuaded by the fact that the creation hypothesis is *ad hoc* in the worst sense of the word.

## 6. *The Ad-Hocness of the Creation Conjecture*

An *ad hoc* hypothesis may be of either of the following kinds: (*a*) covering or "saving" a limited observational domain but, at the same time, lacking any theoretical support whatsoever; (*b*) saving another hypothesis. Inductive or empirical generalizations belong to the first class, whereas the continual creation hypothesis is of the second kind. In fact, this conjecture was launched with the sole purpose of saving the "perfect cosmological principle": "There is only one way in which a constant density can be compatible with a motion of expansion, and that is by the *continual creation of matter.*"[13]

(Actually this is not strictly so: one might also save the "perfect cosmological principle" from being ruined by the expansion hypothesis, by postulating that the rate of light emission in the universe is larger than the rate of light absorption, and that this difference is such that more and more objects could be *seen* were it not for the expansion; and that this greater visibility is exactly counteracted by the increasing thinning out of matter that accompanies

[12] See, e.g., H. Bondi, *Cosmology*, p. 144: "It should be clearly understood that the creation here discussed is the formation of matter not out of radiation but out of nothing".

[13] H. Bondi, *Cosmology*, p. 143.

expansion. This alternative assumption, too, saves the uniformity hypothesis and has the advantage that it is based on observational evidence—in fact, more emissions than absorptions seem to take place at this time in the history of the universe—and contradicts no law of physics. But this is a minor point: the crux of the matter is that the creation hypothesis is *ad hoc* in the worse sense, since its sole function is to protect another hypothesis.)

But why should the "perfect cosmological principle" be saved in detail at all? The reason seems to be the mistaken belief that the constancy of physical laws (a generally accepted hypothesis with an ontological import) is equivalent to the over-all constancy of the universe. In fact, Bondi[14] states the following alternative: "Either the laws of physics, as we have them here and now, apply everywhere and at all times, because the universe has been the same at all times and is the same everywhere, broadly speaking, or cosmology is a very much more difficult subject than I would like to tackle."

Clearly, this is a false alternative: if something is unchanging, then its mode of being (as determined by its laws) is unchanging as well—but the converse does not hold. The constancy of laws only involves the constancy of relations among properties and among events: it does not involve the immutability of the relata. The hypothesis that no event is exactly repeatable is consistent with the hypothesis that the relations involved in events of the same class are constant. Thus, we may never find twice the pair of values $(x_1,y_1)$ characterizing a certain event, but if the metalaw of the constancy of laws is valid, then a certain relation $y = f(x)$ among all possible pairs $(x,y)$ will re-

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14 H. Bondi, in *Rival Theories of Cosmology* (see reference 1), p. 38. See also his *Cosmology*, p. 141.

main constant in time. In other words, unchanging laws may describe changing states—and even irreversible changes of state.

The eagerness to keep the "perfect cosmological principle" seems, then, motivated by a misconception of the nature of natural laws. This point is clear; but how are we to account for the inconsistency between that desire to ensure the applicability of physics everywhere and at all times, on the one hand, and the lightness with which basic laws of physics are thrown overboard by the steady-state theoreticians? Not even the law of conservation of electric charge, which is the best established of all conservation principles, has been spared by the steady-state theoreticians.[15]

The "perfect cosmological principle" is necessitated neither by the metalaw of the constancy of laws nor by empirical evidence. That the average density of matter does not undergo secular changes is, for the time being, an unfounded hypothesis justified only by methodological reasons. It is, in fact, a working hypothesis in the nature of a simplification to be eventually confirmed or corrected by more precise information. By espousing the "perfect cosmological principle" at the cost of giving up the principle of the conservation of matter, the hostility of the whole of physics is gained. Only an invitation "to build a firm connection between the ideas of continual crea-

[15] See, e.g., R. A. Lyttleton, in *Rival Theories of Cosmology,* ch. III. This time, the hypothesis to be saved is that the reddening of light is a symptom of expansion. This is done by supposing that atoms are slightly charged owing to an excess charge of the proton over the electron charge, by about 1 in $10^{18}$. This would be enough for atoms to overcome the gravitational attraction. A further *ad hoc* hypothesis would then be needed to put the atoms together in galaxies, to group galaxies in clusters, and so on.

tion and those of the rest of physics"[16] is obtained in exchange for that irreparable loss.

Now, ad-hocness involves weak or even nil testability. A hypothesis is tested in science both by its observable consequences and by its continuity with the bulk of scientific knowledge.[17] If the hypothesis concerned is *ad hoc,* then its sole test is that which the hypothesis "saves"—a set of instances if it is an inductive generalization, another hypothesis in the second case. The latter is not too grave if the hypothesis happens to be compatible with the bulk of knowledge; but the hypothesis of continual creation, far from enjoying the support or at least the neutrality of physics, definitely conflicts with it, so that it has already been refuted.

Moreover, the whole steady-state theory is *ad hoc* in that it stands apart from physics. In particular, the theory of Bondi and Gold accepts neither Newtonian nor relativistic mechanics, so that "those who wish to work with the steady-state theory must use a dynamics specifically designed for it."[18] This classes the theory with pre-Galilean cosmology, when terrestrial and celestial mechanics were disconnected. It is difficult to understand why this step backward has on occasion been hailed as a revolution. And it is equally difficult to understand how more precise observation could corroborate a theory which clashes with physics. Only a pragmatist emphasis upon predictive power, and the accompanying contempt for theory, might

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16 H. Bondi, *Cosmology,* p. 169. See also F. Hoyle, *Mon. N. R. Astr. Soc.,* **120,** 256 (1960), where it is granted that the "creation field" "presumably arises, if it exists at all, from the microscopic processes of fundamental physics".

17 For a discussion of these and further criteria for judging scientific theories, see M. Bunge, "The Weight of Simplicity in the Construction and Assaying of Scientific Theories", *Phil. Sci.,* **28,** 120 (1961).

18 W. B. Bonnor, *Mon. Not. R. Astr. Soc.,* **121,** 475 (1961), p. 480.

nourish the hope that future observation alone will be able to dispose of the steady-state-theory.

It might be objected that alternative versions of the steady-state theory[19] are compatible with at least a part of Einstein's theory of gravitation. This is true: some versions of the steady-state theory are mathematically compatible with general relativity (except in so far as they violate energy-momentum-stress conservation) ; but, in exchange, they contain indeterminacies that render certain key predictions (such as red-shifts) noncomputable.[20]

The situation is, then, as follows: the more the steady-state theory isolates itself from physics, the less theoretically testable it becomes, i.e., the more difficult it is for it to get the support of physical theory; and the more the steady-state theory compromises with physics, the less empirically testable it becomes. Of course, one may not care much for the usual tests of truth but may on the other hand cherish alternative criteria, such as psychological satisfaction and simplicity of some unspecified kind.[21] But then why claim that the theory one is proposing is scientific? Plato, in writing his *Timaeus,* did not claim the status of a science for the cosmology contained in it: he frankly acknowledged it to be pure myth.

## 7. *The Test of Recent Observation*

Extensive recent observations with the 200-inch telescope at Palomar Mountain,[22] and with the sensitive Cam-

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19 W. H. McCrea, *Proc. Roy. Soc.,* **A, 206,** 562 (1951), and Hoyle, reference 6.

20 Bonnor, reference 18, and Bonnor, and McVittie, reference 9.

21 Bondi, *Cosmology,* pp. 24-25: "the checking of a prediction, which usually forms such a vital link in the formulation [*sic*] of physical theories, does not occur in this field [i.e., cosmology], and we have to rely on less objective and certain criteria, such as how satisfying and how simple a theory is".

22 A. Sandage, *Astrophys. Jour.,* **133,** 355 (1961).

bridge interferometer,[23] speak definitely against the steady-state theory, as was to be expected.

The most important observational test is the magnitude-red-shift relation, which provides an estimate for the rate at which the conjectured expansion proceeds. According to the steady-state theory the universe is steadily expanding with a positive acceleration (deceleration parameter $= -1$) whereas observational data point quite unambiguously to a negative acceleration (deceleration parameter $= +1$), i.e. to a gradual decrease of the expansion rate at the present time. This inference rests, of course, on the hypothesis, shared by the steady-state theory, that the reddening of light is a symptom of expansion.

A second important test is the count-magnitude relation. The various models predict more or less the same relation—which is not surprising, since they all embody the hypothesis that matter is uniformly distributed in space (though only the steady-state theory regards this as a postulate rather than as a working hypothesis). Therefore the claim that the steady-state predictions are closer to the actual counts than the predictions of rival theories "appears to have no weight whatsoever."[24] Even worse: the corresponding relation for radio sources (ie., the count-flux ratio) is remarkably at variance with the steady-state theory: (*a*) the observed number of sources in an important range is about three times larger than predicted; and (*b*) observation points to an exponential decrease of source number with increasing flux density (the correlate of luminosity), whereas the steady-state theory asserts a corresponding increase. In general, observation of radio sources

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23 M. Ryle and R. W. Clarke, *Mon. Not. R. Astr. Soc.*, **122**, 349 (1961), and M. Ryle, *Proc. Roy. Inst.*, **38**, 439 (1961), and *Amer. Scientist*, **50**, 92 (1962).

24 Sandage, *op. cit.*, p. 374..

"appear to provide conclusive evidence against the steady-state model."[25]

Most interesting among the conclusions resulting from examining recent observation is, however, that none of the existing cosmological models fits all available data.[26] Each cosmological theory fits some observational data, and it is even conceivable that some models may correctly hit on several future observations; but none is even fairly consistent with the totality of evidence. In other words, all cosmologies have so far been refuted by observation; and the steady-state theory has, in addition, been refuted by theory, i.e. by its incompatibility with the bulk of physical theory. (Is this surprising in view of the fantastic assumptions and brutal simplifications all cosmological theories contain?) Hence there is plenty of room for more cosmological speculation—*bien entendu,* for grounded and testable speculation, not for science-fiction.

Only a few cosmological hypotheses are likely to be salvaged from the present crisis. Perhaps the following have the best chances: the eternity of the universe, the approximate and large-scale spatial uniformity of the cosmos (i.e. a weakened version of the restricted cosmological principle), the approximate validity of Einstein's gravitation equations, the continual disorganization and reorganization of matter (from the disintegration and synthesis of elements to the dissolution and birth of galaxies), and that something unusual happened to the explored part of the universe about 10,000 million years ago. But in order to proceed to the salvage of these remains, the shipwreck of cosmology must first be acknowledged.

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25 Ryle and Clarke, *op. cit.,* p. 361.

26 See, e.g., Sandage, *op. cit.,* p. 389. The same conclusion will be drawn by anybody looking at Figures 5 and 6 of the first paper cited in reference 23.

## 8. *Concluding Remarks*

The "New Cosmology" is dying of old age: although it is only partially testable, empirical and theoretical tests have worn out the steady-state theory, which—unlike fully scientific theories—has no capacity for either recovery or growth through criticism. The reason for this inability lies in its dogmatic affirmation of the "perfect cosmological principle" and in the no less dogmatic assertion of the "law" of creation of matter out of nothing.

The stanch adherence to the "perfect cosmological principle" is doubly mistaken. First, because we should know by now that no factual hypothesis is perfect. Second, because it is a faulty procedure of theory construction to choose initial or boundary conditions as postulates: particular characteristics, such as the distribution of matter at a given time, do not replace laws but, in conjunction with laws, should enable us to derive testable consequences from the laws. A theory of human population growth would be wrongly built if it chose the present geographical distribution of people as a postulate, instead of postulating laws of population kinematics. Similarly, a cosmological theory ought to regard the approximate homogeneity of the explored universe as a mere provisional generalization of not too many and not too exact empirical data, rather than as a law proper.[27] The reasons for sticking to high-level laws rather than to data, or even to low-level generalizations, are the following. First, laws are logically stronger than data, in the sense that they may subsume data, but not vice versa. Second, laws have the support of data and of further laws—at least if they are genuine laws and not just whimsical equations. Third, a factual theory, though sensi-

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27 The differences between mere generalizations and laws are discussed in M. Bunge, "Kinds and Criteria of Scientific Law", *Phil. Sci.*, **28**, 260 (1961).

ble to experience, must have a minimum stability with respect to changes in specific information if it is to survive the next empirical test, and if it is to grow in response to new information; and such a stability is gained by introducing high-brow theoretical constructs rather than by sticking to data, which latter attitude gives rise to *ad hoc* theories.

The second rigidity we found in the steady-state theory was related to the continual creation hypothesis. This is not a physical law but an *ad hoc* conjecture altogether outside physics, since it enjoys neither the support of physical data nor the support of physical theory: it is the *ad hoc* unsupported support of a controvertible conjecture (the "perfect cosmological principle"). By severing the continuity with physics, the "New Cosmology" abandons the tradition of scientific cosmology and takes the road of all crackpot theories, which are characteristically isolated from the bulk of science. Nothing can justify the rejection of physics in the name of cosmological considerations.[28] Cosmology is a science to the extent to which it is megaphysics. The rest is either science-fiction or philosophical cosmology.

At least four morals can be drawn from the failure of the steady-state theory. First, in order to make science it is not enough to imagine a few, or even a lot, of equations: mathematics does not warrant factual truth. It is always possible to write down a set of equations claiming that they describe some nonentity—e.g., a ghost field can be ascribed any number of wave equations. For a new equation to be accepted as a member of factual science it must be fairly

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[28] Bondi, *Cosmology*, p. 74: "To a greater or lesser extent any creation-type theory of cosmology must be based in the first instance on cosmological considerations rather than on established physical theories". Contrast this avowal with the opening sentence of the book "The aim of this book is to present cosmology as a branch of physics in its own right" (p. vii).

testable and it must respect not only well corroborated theory but also well corroborated and fertile ontological hypotheses, such as the postulate of non-magic and the postulate of lawfulness. Otherwise the barrier between science and science-fiction is torn down.

Second, the failure to empirically refute a factual statement does not entitle us to retain it:[29] positive confirmation is needed besides unsuccessful attempts at empirical refutation.

Third, considerations of simplicity should never be the main guide in theory construction—as they have been in the case of the steady-state theory. In particular, to postulate the simplicity of nature (e.g., the unchanging over-all aspect of the universe in both space and time) is strategically suicide, however much tactically convenient it may be in that it facilitates the starting of work. In most cases simplicity lies in our outlook—always limited though expanding—rather than in things themselves: most often, simplicity is a result of ignorance. To postulate a simple hypothesis as the true definite image of things, rather than as a temporary working hypothesis, warrants therefore the conservation of ignorance.[30]

The fourth and last moral is this. A world-view is scientific to the extent to which it employs science and is self-corrective like science itself. Now, science is permanently in a state of flux. Hence scientific world-views, too, must be changing: to the extent to which they have an element of truth, they are corrigible and must constantly be rebuilt. And, in view of the present crisis in scientific

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29 This applies, in particular, to Bondi's weak statement of the creation "law", according to which the creation rate is much too slow to be empirically detectable.

30 The dangers of simplicism are examined in M. Bunge, *The Myth of Simplicity* (Englewood Cliffs, N. J.: Prentice-Hall, 1963).

cosmology, we should be prepared for a major revolution in our *Weltanschauungen* as soon as that crisis is over — as it will some day unless we manage to turn the world uninhabitable, hence *unanschaulich*.

To conclude. Science-fiction cosmology is interesting not only as a fascinating tale: in addition it offers the philosopher of science an instance of what science is not. And it poses the historian of culture the thorny problem of explaining the gullibility of certain academic circles: why is it that science-fiction cosmology—or, for that matter, Eddingtonian neo-Pythagoreanism, ESP, psychoanalysis, and philosophical psychology—is often accepted as academically respectable, and sometimes even made, by otherwise competent scientists and critical philosophers? And why are such deviations from the "spirit" of science immune to philosophical criticism?[31]

[31] The steady-state theory was philosophically killed several years ago by M. K. Munitz, *Brit. Jour. Phil. Sci.*, **5**, 32 (1954), but apparently this criticism has been as ineffective as Augustine's refutation of astrology in his *Confessions*.

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