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Uniformitarianism in Cosmology: Background and Philosophical Implications of the Steady-State Theory

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Abstract—Philosophical considerations have been essentially involved in the origin and development of the steady-state cosmological theory (SST). These considerations include an explicit *uniformitarian* methodology and implicit metaphysical views concerning the status of natural laws in a changing universe. I shall examine the foundations of SST by reconstructing its early history. Whereas the strong uniformitarian methodology of SST found no support in the subsequent development of cosmology, the idea of a possible influence the global structure of the universe may have on the laws of physics operative in it has been assimilated by the standard big bang theory as it made its remarkable progress in recent decades.

1. Introduction

In 1948 three Cambridge physicists, Hermann Bondi, Thomas Gold and Fred Hoyle put forward the steady-state theory (SST) as a principal alternative to the big bang cosmology. According to the SST, the expanding universe, instead of evolving from the hot big bang, is stationary on the large scale. The dilution of matter due to the cosmic expansion is compensated for by the creation of new matter, and any other global process operative in the universe is regarded as being self-perpetuating. All evolutionary effects are thus merely local, and no distinction between past, present and future can be made for the universe at large.

The 1964–65 discovery of the microwave background radiation, soon afterwards identified by the majority of cosmologists as the relic of the hot big bang, was a crushing blow to SST. As early as the 1950s, after recalibration of extragalactic distances, the pressing time-scale problem that afflicted the standard cosmology for more than two decades[1] had been taken off the agenda. The prevalent opinion was

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[1]That is, the age of objects in the universe was estimated to be greater than the age of the universe as derived from the original Hubble constant in the most popular relativistic models.

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that there no longer existed any necessity for SST. One rarely reads any more about SST in textbooks.[2] On this view, SST looks like an awkward accident in the history of modern cosmology.

This is, of course, very far from the truth. One should recall that SST was the mainspring of cosmology in the 1950s. Its mere presence forced many astronomers and astrophysicists to invest a considerable amount of effort in observational and theoretical work for the purpose of refuting SST. Its advocates, however, fought their case with equal persistence and ingenuity. It can be seen, in retrospect, how much benefit cosmology on the whole gained from this controversy. At least two remarkable achievements, the theory of stellar nucleosynthesis and the development of radioastronomy, have been directly stimulated by SST. At its initial stage, the idea of stellar nucleosynthesis showed a way to account for the observable abundance of elements without recourse to a hot state in the remote past of the universe. That prompted Hoyle to work on this program. By an irony of fate, this contribution was later to become a part of the rival big bang cosmology. First counts of radiosources, on the contrary, gave strong promise of disproving SST. It is not at all obvious that these and some other achievements would have been made so rapidly if there had not been a SST to be defeated.

It proved, however, to be not so easy to defeat SST. The theory 'died' several times, but invariably came back to a new life. This is no wonder. Cosmologically significant astronomical data being scarce and contradictory in those days (as well as today!), the general desire to refute SST quickly, often led to hasty conclusions that were abandoned later on. In such circumstances, debates moved to essentially theoretical issues. The parties were forced to resort to foundational arguments, and this is what makes the history of SST philosophically interesting.

The competition between SST and standard relativistic models in the 1950s was no less important for molding cosmology as a scientific discipline with its particular methods, than were the discussions provoked by the ideas of E. Milne, A. Eddington and P. Dirac in the 1930s (see Gale, 1992; Gale and Urani, 1993). In both cases disagreement about conceptual issues grew into controversies about regulative principles of science in general. The position taken up by Herbert Dingle (1953) was highly symptomatic: he recognized in both nonstandard trends in twentieth century cosmology dangerous signs proclaiming the advent of bad times for all of scientific philosophy. He was right, after all, provided the latter is strictly identified with logical empiricism and the image of science which it provided: bad times were really coming for them in the 1950s. Notably, the development of SST coincided with the counter-positivistic turn in the philosophy of science, and this turn was manifest in the former in at least two ways: (a) with respect to the foundational issues mentioned

[2]A comprehensive history of SST is yet to be written. For brief accounts, see North (1965), Merleau–Ponty (1965), Brush (1992), Kragh (1993). Personal recollections of the main protagonists are contained in Terzian and Bilson (1982). See also Bondi (1988, 1990, 1993).

above and (b) with regard to conflicting views of theory appraisal involved in the debates about the status of SST in the 1950s.

I am going to explore these questions by reconstructing the early history of SST. I begin by recapitulating the two original versions of this theory (Bondi and Gold, 1948; Hoyle, 1948). I shall then dwell briefly on the relations between SST and astronomical observations. First of all, however, I want to identify the common conceptual background of both versions of SST. This background, I think, is to be found in a certain scientific school, the advocates of which were the first to argue explicitly that the methodology used in a science dealing with large-scale evolutionary processes cannot be independent of the particular resulting pattern of the historical unfolding of our actual world. This tradition is known as *uniformitarianism*.

2. Uniformitarianism as a Methodological Principle

Both cosmology and geology belong to what Whewell dubbed 'palaetiological' sciences that are concerned with events that happened in the remote past. The general problem of uniformity is common to all such sciences, though the particular form it takes depends on the context. No satisfactory explanation of the present state of the Earth, or the universe, can be attained without inquiring into the former's geological, or the latter's cosmological, past. But obviously one has no observational access to either. Invoking hypotheses about the past is thus unavoidable in palaetiological sciences. Different schools of thought, however, hold divergent views about what kinds of hypotheses are admissible here.

The basic tenet of the uniformitarian school was that, unless the past of a global system under study is in some important way similar to its present, the freedom involved in hypothesizing about the former is so great that no genuine science of the system at hand is possible. A historically relevant interpretation of the basic uniformitarian requirement admits at least two senses of 'similarity' sometimes blended together (see, e.g. Gould, 1965; Rudwick, 1971; Laudan, 1982). In the *weak* sense, one can require that the *kinds* of processes at work in the geological past of the Earth be the same as at present. Put differently, this weak uniformitarian principle implies the temporal uniformity of natural *laws*. The *strong* uniformitarian assumption goes further and demands that not only the kinds of processes, but their *intensities* be the same in the past as at present.

It should be noticed that the weak principle of uniformitarianism has been shared not only by the historical uniformitarians but also by many of their rivals (Rudwick, 1971). It can reasonably be argued that the constancy of laws is an indispensable assumption of scientific method in general, since no simple generalization of experience is possible without it. The weak uniformitarian thesis was in fact primarily directed against invoking *non-scientific* causes of past events explicitly violating the laws of nature. By itself, this thesis does not entail a particular, *non-developmental* geological scenario. A *directional* theory of geology (like that of the gradually cooling Earth) can be compatible with weak uniformitarianism, provided no currently unobservable *kinds* of processes are introduced to account for the present state of affairs. This by no means rules out a possible change in the *strength* with which the processes operate in various epochs.

Some geologists, and most notably James Hutton and Charles Lyell, believed this was not enough to make geology a science. They insisted that the particular *intensities* of processes, and not only the laws of their operations, should be the same throughout the entire geological history of the Earth. This does not exclude small-scale spatial and temporal fluctuations, and the latter were in fact used by Lyell for explanation of climatic changes and the details of the fossil record. The overall large-scale picture, however, must be essentially *steady-state*. No systematic evolutionary effect (like the Earth's cooling) was allowed in it.

Strong uniformitarianism and the related steady-state pattern have been refuted by subsequent observations that have proved that some drastic changes did occur in the geological history of our planet. As to weak uniformitarianism, it has, in fact, lost its geological identity and become an implicit methodological presupposition of all natural sciences dealing with evolutionary phenomena. Although it poses some restrictions on theorizing, it is generally held that no particular picture of phenomena follows from weak uniformitarianism. One can easily see why this is the case in geology. The whole geological scene is nothing but a local superstructure over the basic level of the physico-chemical laws. The evolution of the 'scene' can proceed against the unchanging background of the underlying laws.

The situation becomes more ambiguous in cosmology where the 'scene' is not a local superstructure built above a more fundamental level, but an all-embracing totality coextensive with the realm of the most fundamental physical laws.

3. Cosmology vs Local Physics: Philosophical Prolegomena to the Steady-State Theory

Philosophical considerations were essentially involved in the version of SST presented by Bondi and Gold (henceforth SST-I). Their seminal paper (1948) begins with an extensive methodological introduction. The history of SST is usually traced back to this work. The philosophy of the steady-state project, however, was already contained in the review of cosmology published by Bondi some four months earlier (Bondi, 1948).

Although there was no mention of the steady-state hypothesis in it, the ground was completely prepared for its introduction in the next issue of *Monthly Notices*. I shall follow both papers in my account of the philosophical foundations of SST-I.

Like his famous predecessor E. Milne, Bondi argued that, because of the uniqueness of its subject, cosmology is very different from 'local physics'. Hence, the cognitive procedures employed in the latter may not be entirely appropriate for the former. In local situations, one can always distinguish between *laws* and their particular *instances*. The laws reflect inherent, unchanging and reproducible features of phenomena, whereas the laws' instances are normally taken to be accidental, contingent and, generally speaking, irreproducible. Indeed, it is not possible to reproduce all conditions of a particular local experiment or observation, for a scientist does not have control over the time and place of their occurrence. It is, according to Bondi, a fundamental assumption of physical science that, while the 'accidental' characteristics of the phenomena under study can obviously be affected by their temporal and spatial location (as well as by the entire collection of initial and boundary conditions), what is regarded as 'inherent', or law-like, cannot be so affected. Otherwise, no coherent physical explanation of the phenomena and processes could be attained.

For example, in any local branch of mechanics, such as ballistics (Bondi, 1948, p. 105), *actual* motions can be infinitely varied by their initial conditions, including times and places of particular occurrences. However, the law according to which the trajectories of all such motions are (approximately) conic sections is supposed to survive all the changing circumstances. Furthermore, it is taken for granted that 'the law of motion does not only cover all the cases corresponding to the various initial conditions but all these cases are supposed to have a real or potential existence'. In this sense, 'the law of motion is neither too wide nor too narrow; it covers all existing and possible cases and no others' (Bondi, 1948, p. 105).[3]

Does the 'ballistic attitude' apply to cosmology? It is not at all obvious. 'The distinction between impossible and possible, but "accidentally" not realized states, becomes absurd when we have to deal with something as fundamentally unique as the universe' (Bondi, 1948, p. 106). In what way can this 'fundamental uniqueness' manifest itself in cosmological theorizing? First of all, it can blur the demarcation line between the laws of nature and their particular instances. The universe is something more than just one particular 'instance' of natural laws; such an 'instance' is virtually coextensive with the laws themselves. With equal reason the latter may be regarded as a consequence of the universe's very existence.

One corollary of these considerations is this: the demarcation between what is 'intrinsic' and what is 'accidental', if it can be drawn at all for the universe as a whole, is not bound to coincide with that typical of local situations. In other words, there are reasons to doubt that observations of various features of the universe will tend naturally and automatically to fall into those pertaining to 'inherent' and those relating to 'accidental', as normally happens with observations performed in the 'local physics'. It is not so clear in advance where to draw a line separating these classes. Take, for example, the two parameters, the constant of gravitation and the Hubble 'constant'. The former is usually held to be 'inherent' and the latter 'accidental'. A

[3]This statement is somewhat misleading. One wonders what *other* cases can there be except existing and possible ones.

measurement of the Hubble parameter, however, gives as unique a result as the determination of the gravitational constant (cf. Bondi and Gold, 1948, p. 252), and furthermore, there are theories in which the gravitational constant itself becomes 'accidental', by virtue of its hypothetical dependence on the cosmological epoch.

The upshot is that as soon as one steps into the cosmological arena, the general 'logical' arguments supporting a particular division of physical experience into 'intrinsic' and 'accidental' subcategories are no longer available. One should draw this division anew, on the basis of some extralogical considerations. The big bang cosmology chose the most straightforward way, that of a direct extrapolation of concepts, laws and 'demarcation principles' of the local physics to the cosmological scale, in the conviction that no problems would arise with this approach. In particular, a tacit agreement has been made to the effect that the global structure of the universe (say, the density and velocity distribution of matter) has no influence over the local physical laws, in the sense that observers performing their experiments in different places and at different times would derive the same laws from their observations. But this is not self-evident. One could recall Mach's principle stating that some local physical properties may be subject to the dynamic influence of distant matter in the universe. Any dependence of this sort would impede the appropriate interpretation of observations of distant objects so essential to cosmology.

According to the authors of SST-I, any possibility of such an influence must be precluded from the very beginning. For this, a very special cosmology is needed; one which would postulate equality and indistinguishability of all parts and all stages of the physical history of the cosmos. Any large enough spacetime fragment of the universe should be a fair sample of the whole.

By adopting the *cosmological principle*, the big bang theory made a first, but insufficient, step in this direction. The cosmological principle postulated the large-scale homogeneity and isotropy of the universe and ensured a uniform description of all parts of the universe at each moment of time, but not for the entire duration of its evolution. Any cosmological theory contemplating local laws in a universe undergoing changes must make, as Bondi later stressed, 'definite assumptions about the effect of these changes on the laws of physics. Even the statement that there are no such effects is evidently an assumption, in fact a highly arbitrary assumption' (Bondi, 1957, p. 197). Indeed, it is not at all clear that the laws of physics discovered here and now, at a later cosmic epoch, would be suitable for dealing with the early evolutionary stages, as depicted by the big bang cosmology, when the matter of the universe is supposed to have been in a rather different physical state.

One could adopt another strategy and posit a possible explicit dependence of the laws on the changing physical structure of the universe, as was done by Dirac (1937), or (somewhat anachronistically, but to the point) by Brans and Dicke in their scalar–tensor theory of gravity (1961). Generally speaking, many possibilities arise at this point, this freedom being a defect, rather than an advantage, of the received methodology. For, again, there is only one universe, and its evolution is perhaps the unique cosmic event. It would not be unreasonable to require that the scientific picture of this event be also 'unique' so as to cover 'all existing and possible cases and no others' (Bondi, 1948, p. 105).

The most radical way to avoid these problems, as well as arbitrary assumptions concerning possible effects of the changing cosmological environment on the physical laws, is to exclude such effects altogether, by extending the cosmological principle. The *perfect cosmological principle* (PCP) requires the large-scale structure of the universe to be not only uniform in space but also constant in time. 'We do not claim that this principle must be true', Bondi and Gold observed, 'but we say that if it does not hold, one's choice of the variability of the physical laws becomes so wide that cosmology is no longer a science. One can then no longer use laboratory physics without relying on some arbitrary principle for their extrapolation' (Bondi and Gold, 1948, p. 255).

The uniformitarian leitmotiv is clearly recognizable in this claim. The situation is unlike that in geology, however, as the distinction between weak and strong versions of the uniformitarian assumption disappears in steady-state cosmology. The whole point of Bondi and Gold is that once we let the 'intensities' of physical processes in the past of the universe be drastically different from what they are at present, no guarantee can be given for the stability of physical laws themselves across the entire evolutionary track.

4. Laws of Nature in a Changing Universe

In their argument in favor of PCP Bondi and Gold raise a number of questions that are only briefly mentioned by them, if at all. Some of these questions regarding the notion of a natural law have a genuine metaphysical import and need further clarification.

(1) One has an impression that a shift of meaning somehow occurs throughout the discussion of the issue 'cosmology vs local physics' in Bondi (1948), in Bondi and Gold (1948) and also in later works (see, e.g. Bondi, 1957, 1960). Indeed, the argument starts with the locally ascertainable distinction between the laws of nature and their particular instances. Such a distinction, then, is supposed to vanish or become blurred with respect to the entire universe. This seems to imply something like a 'law of the universe' in the first place. Even if this hypothetical law collapses with its only instance, becoming thus 'degenerate', it still has to possess some distinctive features of a law. Otherwise there is no reason to call it by that name. No examples of this type of law are given, though, and one wonders if there can be any. This does not impair the main argument, since the latter essentially hinges on quite a different usage of the term 'law', to which the discussion eventually switches.

As a matter of fact, it is the familiar laws of local physics that may be nonuniformly affected by the structure of the universe, unless one adopts the perfect cosmological principle, making such an influence uniform and hence imperceptible. 'As the physical laws cannot be assumed to be independent of the structure of the universe, and as conversely the structure of the universe depends upon the physical laws, it follows that there may be a stable position,' Bondi and Gold remark (1948, p. 254). Clearly they mean the local physical laws acting *in* the universe, and not some hypothetical law *of* the universe. It would be appropriate to assume, then, that in the steady-state universe satisfying PCP, the action of a local law may, in the general case, consist of the two components: (a) an intrinsic local 'source' and (b) a uniform global cosmological 'contribution'. Of course, there may be no such 'contribution' at all. But even if there is, PCP guarantees the universal validity of the same local laws in the range of the whole universe and at any moment of time.

(2) But if so, one has another problem. If the local laws in fact carry an 'imprint' of the universal structure, how can we reconcile the supposed uniformity of laws on a small scale with the pronounced *non-uniformity* of the universe on this scale? Neither Bondi, nor Gold ever addressed this interesting problem naturally arising in their theory. As we shall see later on, the problem has outlived the theory and proved its importance. The influence of the universe's structure on the laws operative in it can in fact be a real and not just an imaginary phenomenon, the possibility of which should be taken seriously.

(3) But then one more significant question arises: how should the presumed *bilateral interaction* between the laws of nature and the material content of the universe be conceived? Bondi and Gold frequently quote Mach's principle in this connection. Mach's principle, however, is ambiguous, and doubts certainly arise as to whether it can be a paradigm example of the distant matter's effect on the local *laws*. In any case, Bondi and Gold refer to Mach's principle as if it were just one manifestation of a general *interaction principle*, the latter equally pertaining to all local physical laws (none of which, we recall, was supposed to be insured against a possible influence of the structure of the universe).

Now, the primary problem is not in a particular mathematical form by means of which such a possible interaction could be described. Before inquiring into such forms one should find out whether the interaction principle is generally acceptable from the metaphysical standpoint. The answer depends almost totally on what one means by a law of nature.

Unfortunately the authors of SST do not express their metaphysical views on this matter explicitly, whereas their occasional remarks reveal a certain ambiguity. Thus they often associate the physical laws with the 'intrinsic' or 'inherent' properties of reality. At the same time, they refer to them as 'the abstract things' (Bondi and Gold, 1948, p. 253). Abstract things may be of rather different sorts, the familiar examples being Platonic ideas, numbers or linguistic constructions. None of these things can be influenced by material things.

If, on the other hand, physical laws are identified with natural necessities, or intrinsic properties of nature, 'influence' of the requisite sort appears to be a viable metaphysical alternative. Intrinsic properties of nature are not something distinct from the former; it might be reasonably conjectured that the properties inherent in a changing nature could change themselves—not owing to some specific 'interaction' or 'influence', but just by virtue of their mode of existence. They are indistinguishable from nature itself, or, in Bondi and Gold's words, 'we cannot have any logical basis for choosing physical laws and constants and assigning to them an existence independent of the structure of the universe' (Bondi and Gold, 1948, p. 253).

Therefore, one can easily make sense of the 'interaction principle' by identifying the physical laws with the inherent natural necessities. Such an identification, however, would be incorrect. The term 'physical law' normally denotes something else—not the natural properties themselves but rather their expression in the language of science. Like the majority of physicists, Bondi and Gold seem to use the term 'physical law' to denote a conceptual structure whose elements' relations are expected to represent the relations among nature's inherent properties and characteristics. The authors of SST-I, further, use the terms 'influence', 'interdependence' (of laws and objects in the universe) and the like to denote (unspecified) conceptual structures that could be invoked to represent some interaction processes presumably taking place in nature. Once this referential aspect of the whole problem of interaction is recognized, the original uniformitarian methodology of SST should be significantly qualified.

(4) Suppose certain inherent properties of nature are really affected by the material arrangement of the universe. According to Bondi and Gold, the only way to save cosmology as a science in such a situation would be to adopt a strong uniformitarian principle rendering the arrangement of the universe constant. Yet there seems to be another way out somewhat similar to the weak form of uniformitarianism. One could simply incorporate the influence at hand into a more comprehensive conceptual structure (i.e., a law of physics). The former, less comprehensive law may indeed prove to be dependent on the contingent evolutionary conditions. But the *form* of this dependence (i.e., a new conceptual structure), once discovered, can be called a new law of nature.

This new law, to be sure, may also be 'compromised'. But nothing prevents one from repeating the whole procedure all over again. We are certainly dealing with a step-by-step process here.[4] But the development of science is precisely such a process. Thus, to keep cosmology within the boundaries of science one need not be a strong uniformitarianist.

An obvious objection may be that to discover the form of dependence of the former ('compromised') law on the material conditions that presumably took place in the early universe, one has to have access to these conditions, which one has not. As noted

[4]Whether this process can be successfully accomplished in all conceivable cases, in order to preserve the constancy of the currently most comprehensive law, is an interesting question which I will not pursue here. See Balashov (1992).

by all steady staters, room for unrestricted speculation opens at this point. It is precisely for the purpose of banning such speculation about unobservable causes that the uniformitarian methodology should be adopted in cosmology, as it was adopted in geology more than a century earlier.

It seems, however, that this 'speculation argument' cannot be employed in a wholesale and unspecified way. It became clear in the late 1940s that certain conditions, namely those pertaining to the primordial nucleosynthesis epoch of the early universe, can be duplicated in the terrestrial laboratories. Later on, the conditions covered by such a duplication were extended up to the electroweak separation epoch ($T \sim 10^2$ Gev, $t \sim 10^{-11}$ s, according to the big bang model). True, they have not been extended beyond this point, and there are strong reasons to believe that there is a certain point beyond which they cannot be extended in principle. Does this mean, however, that the danger of 'speculative freedom' is so severe that, ultimately, one must either succumb to strong uniformitarianism, or abandon the idea of scientific cosmology altogether?

This is where the great divide still lies. The non-uniformitarian cosmological case can be based on two points. First, the reconstruction of the physical history of the big bang universe up to the point where the primordial conditions can still be duplicated in the laboratory may turn out to be empirically successful. Hence, the hypotheses pertaining to them (including those concerning possible evolutionary changes in the laws of physics) can be *independently* validated. If this is the case (which in fact it is), such a success cannot be simply ignored by a rival theory. Second, the hypotheses concerning the earlier, non-duplicatable conditions can in principle be justified *retroductively*, by looking at their consequences for the present astronomical picture.

Now the reliability of such a cosmological retroduction can be legitimately called into doubt, if the only reason for accepting a certain hypothesis regarding the remote past of the universe is its ability to deal with meager and contradictory astronomical facts for the explanation of which it was originally introduced. The negative attitude some scientists bear toward the big bang cosmology is partly due to these problems with retroductive evidence. The advocates of alternative approaches, including the modern modifications of SST (see, e.g. Arp *et al.*, 1990), have a right to disregard the merely retroductive evidence in favor of the big bang model. As already stated, however, they cannot ignore its genuine empirical success backed by the independent corroboration of the hypotheses about the early universe conditions. Theirs is the burden of providing an alternative explanation for all the relevant facts successfully explained in the received theory.

The situation, however, was very different in 1948. No sign of the spectacular success of the big bang cosmology that occurred some two decades later was present. Quite the reverse, the big bang cosmology was in a very poor condition, unable to deal properly with the time-scale problem, to explain how galaxies could have been formed and how the observable abundance of chemical elements could have been produced. The scene was effectively set for the introduction of a principal uniformitarian alternative to the hot big bang.

The problems discussed above will now be put aside and the exposition of SST-I will be returned to.

5. The Perfect Cosmological Principle

The entire content of SST-I was expected to be deducible from the perfect cosmological principle (PCP) postulating the large-scale uniformity of the universe in space and time. Bondi and Gold considered it of crucial importance to stress that PCP and the cosmological principle (CP) of the big bang theory (assuming the universe to be uniform in space but changing in time) differed not only in their formulations but also in their status in the corresponding theories. According to Bondi and Gold, CP is no more than an auxiliary hypothesis needed to derive a particular empirically adequate cosmological model from the field equations of general relativity. Should a conflict arise between a model and the astronomical data, CP could well be replaced with a more complicated assumption without abandoning the conceptual basis of the big bang theory.[5] In SST-I, on the contrary, PCP was supposed to be an essential element. SST-I and PCP stand or fall together, for, as Bondi and Gold invariably stressed, the scientific value of cosmology derives from the strong uniformitarian assumptions inherent in PCP.

On this view, the 'rank' of PCP is higher than that of the ordinary physical laws, for the very *raison d'être* of ordinary physical laws hinges on the validity of PCP. As Bondi and Gold note in this connection, 'we regard the principle as of such fundamental importance that we shall be willing if necessary to reject theoretical extrapolations from experimental results if they conflict with the perfect cosmological principle even if the theories concerned are generally accepted' (Bondi and Gold, 1948, p. 255).

The main target here was the principle of conservation of matter and energy. To satisfy PCP in an expanding universe, the creation-of-matter hypothesis was introduced, in order to keep the density of cosmic matter constant.[6] The rate of creation required for it turns out to be too low to be discoverable by any observational effects. As the universe expands, new matter is created, thereby leading to local evolutionary phenomena, like the formation of new galaxies and stars. There is,

[5]This is hardly so. Though CP can be referred to as an auxiliary hypothesis, nobody has been able, since 1917, to construct a reasonable cosmology without it and this seems unlikely to be at all plausible. As an auxiliary hypothesis, CP has become indispensable to the standard model no less than PCP was to SST of Bondi and Gold.

[6]In SST-I, this rate corresponded to the emergence of 1 hydrogen atom per 1 m^3 every 3×10^5 years.

however, no large-scale evolution in this picture. Any sufficiently large fragment of space contains objects at all stages of their development. No global feature of the universe, such as the mean density of matter, the integral luminosity, or the spectral distribution of radiation, is subject to a systematic temporal change in SST.

In other words, any large-scale process operative in the steady-state universe should necessarily be self-perpetuating. This feature of the theory can be illustrated by the mechanism of galaxy formation elaborated by Sciama (1955) in the framework of SST. New galaxies were supposed to form permanently in the wake of the old ones, the latter moving through space served as attractors of intergalactic matter, including its newly created fraction. The subsequent separation of the daughter and mother galaxies provided for the continuous rejuvenation of the cosmic population, keeping its average age constant. Unlike the big bang cosmology, SST allowed no unique 'catastrophic' event associated with the *original* formation of galaxies in the remote past.

To ensure the steady state of the universe, Bondi and Gold had thus sacrificed the conservation laws. From the consistent cosmological point of view which Bondi (1957) later expounded, this was not a deadly sin. Although creation events constitute anomalies contradicting the conservation principle, these anomalies are too small to be manifested in any observable effects. In actuality, the conflict is only between the creation hypothesis and the simplest *theoretical generalization* (namely, the laws of exact conservation of matter and energy) of multitudinous experimental facts testifying that energy is conserved with great accuracy. However, inference from experience to theory should not ignore the *cosmological point of view*. The cosmological case is not just one instance of local physical laws. The latter have their locus in the expanding universe. Any statement of their form is at the same time a statement of the global properties of the unique physical whole, the universe. The creation process required by PCP implies violation of the *exact* conservation principle thereby substantially reducing its simplicity, but this is 'more than counterbalanced by the gain in simplicity' in the resulting cosmological model (Bondi, 1957, p. 196). On this view, 'continual creation is the simplest and hence the most scientific extrapolation from the observations' (Bondi, 1960, p. 144).

One can see combined in this argument a highly inductivist interpretation of the fundamental conservation principles of physics and an utmost hypothetico-deductivism with respect to the cosmological model at hand. Whether or not one is willing to accept this argument, there is nothing impossible or even peculiar in this combination, which is entirely consistent in its own right. One should certainly agree with John North (1965, p. 210) that it was naive to reject (as many physicists in fact did) an empirically successful theory (which SST was in the early 1950s) for this reason alone, that 'some inviolable Principle of the Conservation of Energy' is violated in it.

6. The Perfect Cosmological Principle and General Relativity

Yet the PCP is definitely in conflict with the field equations of general relativity, for the latter's mathematical formalism requires strict conservation of energy. Therefore, Bondi and Gold could not employ the available theory of gravity in deriving their model. Remarkably, no theory of gravity at all was needed for that. Bondi and Gold (1948, p. 260) proceeded from the generic Robertson–Walker metric for homogeneous and isotropic models that was shown to be obtainable independently of any particular dynamical theory:[7]

$$ds^2 = c^2 dt^2 - R^2(t)(dr^2 + r^2 d\theta^2 + r^2 \sin^2\theta d\varphi^2)\left(1 + \frac{kr^2}{4}\right)^{-2}, \qquad (1)$$

where (r, θ, ϕ) are constant coordinates of a fundamental particle partaking in the cosmic expansion, $k = -1, 0, 1$ is the parameter defining the geometry of a particular model and $R(t)$ is an arbitrary function of time usually called 'scale factor' in the relativistic models.

The steady-state model can be formally derived from (1) in the following way (see, e.g. Bondi, 1960, pp. 145–146). The square of the radius of curvature of the (r, θ, ϕ) space, $\frac{k}{R^2}$, is responsible for certain observable effects[8] and, hence, according to the PCP, must be constant. Since obviously $R(t) \neq$ const,[9] this gives $k = 0$. The Hubble parameter H is also an 'observable'.[10] From $H = \frac{\dot{R}}{R} = \text{const}$ it follows that $R(t) = \exp(Ht)$. Thus the metric of the stationary universe is

$$ds^2 = c^2 dt^2 - (dr^2 + r^2 d\theta^2 + r^2 \sin^2\theta d\varphi^2)\exp(2Ht) \qquad (2)$$

which formally reproduces one of the early de Sitter solutions, as expressed by Lemaître and Robertson (see North, 1965, p. 112).

Whether this formal similarity has any physical meaning depends on SST's attitude toward the received field theory of gravitation. Bondi and Gold discuss this problem in detail. Because of the violation of conservation principles, it is not possible to incorporate the steady-state model into general relativity. It may, however, be possible to proceed the other way round and to derive the proper theory of gravity from SST-I, as a consequence of PCP (Bondi and Gold, 1948, p. 270). From the cosmological point of view, this procedure would be entirely legitimate. For PCP has a priority over any particular physical law, and the methodology of SST-I assumes that implying laws

[7]This metric was derived by H. P. Robertson and A. G. Walker in 1935–36 from the kinematical consequences of Milne's cosmological principle under an assumption very similar to Weyl's postulate (see text). See, e.g. Bondi (1960, pp. 129–130, 145).
[8]For example, the number of galaxies observable in the unit proper volume of space.
[9]Otherwise there would be no redshifts in the spectra of distant galaxies.
[10]It accounts for the receding of galaxies.

from cosmological considerations is at least as fundamentally important as a general formulation of the laws.

In this sense, argue Bondi and Gold, the theory of gravity underlying the big bang cosmology is not entirely satisfactory. Locally, it proclaims an equality of all reference frames. At the cosmological level, however, the equality is violated owing to adoption of the *Weyl postulate* which is nothing but a mathematical corollary of the cosmological principle. According to the Weyl postulate, the world lines of the 'fundamental particles' partaking in the general expansion of the universe are geodesics orthogonal to the spatial hypersurfaces $t = \text{const}$. The existence of such hypersurfaces and hence of t, the 'cosmic time', is due to the uniformity of the universe in the smoothed-out model. Consequently, at each point of space-time there exists a time-like vector associated with the state of motion of a 'fundamental particle' and an observer moving with such a particle is privileged in the sense that she sees a strictly isotropic expansion picture.

The geometrical structure of the expanding universe is thus manifestly non-invariant, for it naturally gives rise to a preferred vector field. This field, however, plays no role in the general formulation of the received gravitation theory. Because of this, write Bondi and Gold, the latter becomes too wide: 'It covers a far greater range of possibilities than actually exist' (1948, p. 268). An additional postulate (namely, that of Weyl) is then invoked to narrow down this range. 'To us this narrowing-down of the theory in its final form seems to be utterly unsatisfactory, these restrictions should enter the theory at the beginning and not at the end' (Bondi and Gold, 1948, pp. 268–269). There is no reason to require a complete invariance of the laws of nature while assuming that their most important application, corresponding to the unique structure of the universe, is clearly non-invariant.

SST, Bondi and Gold hold (1948, p. 266), has an important advantage over the relativistic cosmology in that it attributes a direct physical meaning, and not only a geometrical meaning, to the field of privileged vectors imposed by the cosmological principle by identifying these vectors with velocities of the newly created particles of matter. Because of its universal significance, the vector field defined in this way should play as essential a role in the general formulation of the gravitation theory as the tensor field.

The existing theory of gravity should thus be substantially modified. Bondi and Gold promised to present in another paper, a formulation of the field theory free from the above objections (1948, p. 270). This idea, however, was eventually completely abandoned. Later on Bondi gave reasons for that: 'We feel that, as the assumption that the universe is in a steady state leads to observable consequences without any field theory formulation, no advantage is gained by tackling now the obscure and highly ambiguous problem such a formulation presents' (Stoops, 1958, p. 78).

Yet a gravitation theory formulation satisfying, in many respects, the above requirements and leading to a steady-state model of the expanding universe already existed at the time Bondi and Gold's original paper came out, and awaited its appearance in the next issue of *Monthly Notices* (Hoyle, 1948). Moreover, this theory had been criticized by Bondi and Gold in their paper before it was actually published.

7. Hoyle's Theory

The author of SST-II was less concerned with philosophical problems. He posed a physical question instead: where did the observable matter of the universe come from? There are two main alternatives: either it was created all at once in the remote past, or it was, and now continues to be, created as the universe expands. The one-time 'catastrophic' creation-in-the-past implicit in the big bang cosmology was, Hoyle wrote (1948, p. 372), 'against the spirit of scientific inquiry', for the theory, in fact, deals only with the already created matter and does not consider the process of creation itself.

Pushing the awkward question of creation of the material content of the universe back to the past is, one could say, quite similar to invoking suitable catastrophic events in the geological history of the Earth in order to account for its currently observable features. In geology this approach has been severely criticized and rejected by the uniformitarians. In cosmology, almost the same sort of criticism was represented by the steady staters, who suggested that severe constraints should be placed on cosmological speculation about the remote and inaccessible past of the universe by postulating that the processes that have occurred in the past are basically the same as those going on in the universe now. The most important process of this kind is the continuous creation of matter. Hoyle insisted furthermore that, because of its fundamental importance, this process should be *explained* and not simply postulated, as was done in SST-I. Contrary to the 'philosophical' approach of the latter, he suggested a mathematical account of the creation process, by way of modification of the field equations of general relativity.

This is reminiscent of the first steps taken in relativistic cosmology. In 1917 Einstein modified his field equations of gravitation in order to get the static model of the universe. Hoyle aimed to justify a stationary picture. By invoking the Einsteinian precedent, he too introduced an additional tensor term into the equations of general relativity:

$$R_{\mu\nu} - \frac{1}{2} R g_{\mu\nu} + C_{\mu\nu} = -\frac{8\pi G}{c^4} T_{\mu\nu}, \tag{3}$$

$$\text{where } C_{\mu\nu} = C_{\mu;\nu} = \frac{\partial C_\mu}{\partial x^\nu} - \Gamma^\alpha_{\mu\nu} C_\alpha \text{ and}$$

$$C_\mu = \frac{3c}{a}(1,0,0,0),\ a = \text{const.}$$ [11]

The vector C_μ, which is parallel to a geodesic at each point of the homogeneous and isotropically expanding universe (thus satisfying the Weyl postulate), represents

[11] Here $C_{\mu\nu}$ is a symmetrical tensor obtained by covariant differentiation of C_μ. $\Gamma^\alpha_{\mu\nu}$ are Christoffel symbols.

precisely the vector field that Bondi and Gold expected should play as fundamental a role in the general formulation of the gravitation theory as the tensor field.

Under the normal assumption that the only non-vanishing component of $T_{\mu\nu}$ is $T_{00} = \rho c^4$,[12] a solution of (3)

$$ds^2 = c^2\,dt^2 - (dx_1^2 + dx_2^2 + dx_3^2)\exp\left(\frac{2ct}{a}\right) \tag{4}$$

is of a de Sitter type and gives the metric of the stationary universe (Hoyle, 1948, pp. 375–377). Of course, the density of matter in SST-II, unlike that in the de Sitter model, is a constant non-zero quantity given by

$$\rho = \frac{3c^2}{8\pi G a^4}. \tag{5}$$

It can be shown that the vector field C_μ is responsible for the creation-of-matter process. From Eqn (3) we have:[13]

$$(C^{\mu\nu})_{;\nu} = -\frac{8\pi G}{c^4}(T^{\mu\nu})_{;\nu}.$$

Since $(C^{0\nu})_{;\nu} \neq 0$, a continuous creation of matter and energy uniformly occurs.

The only free parameter in Hoyle's theory is a, and it can be adjusted to fit the actual redshift data. By (5), these data uniquely determine the value of the matter density, which makes SST-II more specific than SST-I, where no constraints are imposed on ρ. On the other hand, the steady-state metric (4) is not the only possible solution of (3). In this sense, Hoyle's theory lacks some of the philosophical appeal inherent in SST-I, as being 'too wide'. Unlike the authors of SST-I, however, Hoyle did not attach much importance to philosophical considerations. In his next paper (Hoyle, 1949) he criticized SST-I for the lack of a rigorous mathematical theory and the dubious status of the PCP. On Hoyle's view, such a principle 'should follow as a consequence of primary axioms of the field form . . . and should not appear itself as a primary axiom' (1949, p. 371).

It must be clear from the above that SST was not a single theory. Its two main versions were based on rather different foundations. Whereas SST-II was a typical mathematical hypothesis, SST-I constituted a rare example of a scientific theory developed directly from explicit philosophical arguments. Whereas SST-I, because of its logical rigor, was difficult to develop further, SST-II turned, in fact, into a research program, a chain of modifications continuing up to the present. To be sure, many consequences of SST-I and SST-II were basically the same, and their authors,

[12]The normal assumption amounts to neglecting both kinetic energy and pressure terms of $T_{\mu\nu}$ in the co-moving reference frame.

[13]The divergence of $R_{\mu\nu} - \frac{1}{2}Rg_{\mu\nu}$ is identically zero, due to the properties of the metric tensor $g_{\mu\nu}$.

together with some other converts (D. Sciama, W. H. McCrea *et al.*), formed a single front in their struggle with the common big bang rival in the 1950s.

Yet the situation was most unusual. Three closely related physicists simultaneously proposed two highly non-standard cosmological theories, one (SST-I) being based on the deductions of physical consequences from the 'philosophical' PCP, and another (SST-II) proceeding from modified equations of general relativity. The incompatibility of both theories with the generally accepted scientific views was conspicuous. The author of SST-II then attempted to reconcile his concept with general relativity by successively modifying the former and utilizing the notorious uncertainty of some notions of the latter.[14] The authors of SST-I, on the other hand, having established the incompatibility of their theory with general relativity (and, in fact, with the rest of physics), did not take any steps toward reconciliation. Does it mean that they rejected general relativity (and the 'rest of physics')? Not at all. During these years Bondi, for example, made his famous contribution to the theory of gravitational waves, and Gold worked very productively in several areas of astrophysics.

Another notable feature of both theories (especially SST-I) is that the time-scale problem usually held to have been the most compelling, if not the only, rationale for postulating an eternal steady-state universe is given very little attention in the 1948 papers. In fact, Bondi and Gold's paper can give the impression that the authors' primary concern was to establish their non-standard (i.e. uniformitarian) methodology in the area of cosmology, and not to address the pressing empirical problems.

This impression is deceptive. To clarify this and other questions mentioned above, let me turn to some of the circumstances surrounding the creation of SST.

8. The Scene

8.1. The Time-Scale Problem

There are reasons to believe that all the principal protagonists of SST took the time-scale problem very seriously (see, e.g. Bondi, 1982, 1990, 1993; Gold, 1982; Hoyle, 1982), perhaps even more seriously than their opponents, who continued to adhere to the big bang model in the hope that the problems would somehow resolve themselves (which indeed eventually happened). This is not to dispute the fact that in the fully fledged SST (especially in SST-I), this empirical problem is given little attention. Having been created, theories may assume structural forms not foreseen at the stage of creation. Of course, the context of a theory's creation may differ considerably from that of its subsequent justification. As to SST-I, its form seems to have been entirely subordinate to the justification strategy, and this strategy was essentially *non-inductivist*. The history of SST reflected the philosophical climate of the late 1940s–early 1950s, when the disintegration of the verification doctrine of

[14]Hoyle (1949, 1958, 1960). See also McCrea (1951). I shall not trace this and subsequent development of SST-II in this paper.

logical positivism was accompanied by the emergence of new concepts of scientific rationality.

These circumstances were not of crucial importance for the authors of SST who were, after all, physicists and not philosophers. They were, however, circumstances which certainly provided a favorable background from which additional support for a theory could be drawn. Yet the main reason that Bondi, Gold and, to a certain degree, Hoyle laid stress on the evidential aspects of their theories was the fact that by the end of 1940s cosmology had matured enough to start recognizing itself as a genuine *empirical* discipline. Still more important is the fact that the emergence of SST itself was highly conducive to shaping cosmology as an empirical science.

The empirical aspects of SST shall be examined in the next section. Let me now make a brief excursus into the 'external' history of science in order to understand why three physicists working together came up with two different theories.

8.2. Tommy, Fred and Others

The idea of the steady state was first proposed by Thomas Gold in 1946 or 1947.[15] Gold's hypothesis was directly relevant to the time-scale problem that plagued astrophysicists at that time, but was formulated in so general a form that there was no question of immediate publication. Besides, at that stage the authors considered it unacceptable to infringe upon the conservation of energy and put work on the model aside for a while.

Then, as both Bondi and Gold recall, Hoyle started to act independently. At the end of 1947 he came to the conclusion that the obvious objection against the steady-state hypothesis—that it violates the conservation of energy—is at best ambiguous. He decided to find out whether there was a way to incorporate the creation of matter into the conceptual framework of general relativity. He succeeded in a couple of months and wrote his paper, which, after some unexpected delay, he submitted to *Monthly Notices* five months later.

According to Hoyle, Bondi's interest in a new model of the universe reawakened after he had read Hoyle's manuscript in March 1948. Bondi (1982) and Gold (1982) give a somewhat different version of events. They wanted to make Gold's idea fit for publication from the very beginning, but did not share Hoyle's mathematical approach, of which they knew at an early stage. By that time, Bondi and Gold's 'philosophical' project was already under way in the form of PCP backed by the uniformitarian methodological assumptions and implicit metaphysical views concerning the interdependence of laws and the material structure of the universe. But this was still insufficient for publication. 'We were both a little bothered', Bondi recalls, '. . . that something that had originated with Tommy and on which we all had

[15]The material of this subsection is mostly based on personal recollections of Bondi (1982, 1990, 1993), Gold (1982) and Hoyle (1982) that sometimes diverge. All of them, however, acknowledge Gold's priority in the genesis of the main concept of the stationary universe.

worked was likely to be made public on the basis of what we regarded as uninteresting computations' (Bondi, 1982, p. 60). 'There was Gold's idea, there was our philosophy that was beginning to form, but you cannot publish a paper in physics/astronomy on an idea and a little bit of philosophy' (Bondi, 1990, p. 193).[16] The 'peg' on which the publication could be hung was ultimately found in Hubble's counts of the number of galaxies (N) with luminosity exceeding a given value (S). A characteristic dependence $N(S)$ that could easily be derived from PCP was in good correspondence with Hubble's data.[17] The existence of empirical consequences lent scientific value to the philosophical concept on which SST-I was built.

Hoyle, as mentioned earlier, never had any sympathy with this approach.[18] Personal preferences sufficiently explain the unusual circumstances of the appearance of SST-I and SST-II. It only remains to add that Bondi and Gold's paper, submitted two weeks earlier than Hoyle's, came out first. Not surprisingly, it contained a critique of the paper by Hoyle to be published four months later.

8.3. The Sources of the Philosophy of SST-I and the Status of PCP

We can now see that the philosophical basis of SST-I belongs to the 'context of justification' and not to the 'context of discovery'. Bondi (1990, p. 192) endorsed this much: 'The idea of the steady-state universe certainly came first; the philosophy came afterwards.' Where did the latter come from?

To answer this question, let me recall that the philosophy of SST-I comprises two closely related elements: the explicit uniformitarian methodology and the implicit 'interactionist' metaphysics (underlying the supposed interdependence of physical laws and the material structure of the universe). The sources of the former have been outlined in Section 2. As to the latter, I have noted already that Bondi and Gold derived the 'interactionist' metaphysics from the uniqueness of the universe. Though this derivation is open to certain questions (considered in Section 4), the argument 'from the uniqueness of the universe' has since then become very popular in the literature on the philosophical foundations of cosmology (see, e.g. Munitz, 1962; Agazzi and Cordero, 1991). Strangely, Bondi and Gold's authorship of this argument is seldom mentioned if at all, in these later discussions. What is never mentioned is that the argument of Bondi and Gold was in fact in many ways inspired by that of Milne, formulated in the context of his 'kinematic relativity' in the early 1930s.

Bondi and Gold owe to Milne the key idea of *subordination* of the 'local physics' to the cosmological view of the world. This idea ultimately gave rise to the deductive

[16]As we saw, however, the philosophy of SST-I had already been published by Bondi as a separate part of his review of cosmology (Bondi, 1948).

[17]The slope of the curve lg$N$ vs lg$S$ was later to become the most decisive test of SST by the counts of radiosources. More on that in the next section.

[18]Hoyle's credo is most clearly expressed in his interview with A. Lightman. See Lightman and Brawer (1990, pp. 51–66).

character of both cosmologies, but in rather different ways. In the kinematic relativity it took the form of a grandiose attempt at deducing all 'terrestrial' physics from cosmological considerations without resort to empirical data (see Gale, 1992). In SST-I it resulted in an empirically oriented hypothetico-deductive strategy.

Indeed, Milne's *cosmological principle* was no less than an *ontological* requirement, which the universe was required to meet. PCP definitely lacks this ontological dimension. A universe in which PCP is not valid is no less possible than the universe in which it is presumably satisfied. What is, according to Bondi and Gold, impossible in such a universe is a science of cosmology. But again, serious doubts arise about whether the standard big bang cosmology would be possible in a universe not satisfying even the (narrow) cosmological principle.

Nonetheless, there is undoubtedly a very important difference between PCP and the narrow cosmological principle. PCP makes far stronger assertions about the large-scale structure of the universe, excluding in principle any global astrophysical evolutionary effects. This made the empirical adequacy of SST-I noticeable and this immediately attracted new adherents (especially among the younger physicists) as well as opponents. Both adherents and opponents of SST recognized that the restriction it imposed on possible global evolutionary effects gave it the ability to make more definite predictions than the big bang theory. On the contrary, the advocates of the big bang models reserved the right to make use of a variety of evolutionary mechanisms for explaining a great many astronomical data. As Bondi and Gold observed, testing such a theory degenerates into its permanent modification. A true test, according to them, is possible only in SST (Bondi and Gold, 1948, p. 262), since its empirical consequences admit none of the flexibility characteristic of the relativistic models.

But why is a 'true' testing incompatible with the modification of a theory? This maxim came from the contemporary philosophy of science.

8.4. SST and Falsificationism

Bondi's explicit commitment to the Popperian view of science was an important aspect of the argument in favor of SST partly shared by other steady staters. The degree to which Bondi and Gold's model fitted into the falsificationist account of theory appraisal can be compared with the extent to which it ran counter to the positivist criteria of meaning. Indeed, SST-I was a bold hypothesis based on manifestly metaphysical foundations. Its prima facie priority over the standard cosmology was due to its greater falsifiability. Because of its rigorous form and a complete lack of flexibility it could naturally be made a 'sitting-target' for testing.

Now the fact that, despite their cosmological idiosyncrasies, all the steady staters continued working very actively in different areas of 'standard' physics can also be explained in accordance with the falsificationist code of rationality. No commitment to a particular hypothesis is required of a scientist. All that is required is that a hypothesis be bold, original and falsifiable and that a scientist be prepared to abandon it as soon as it is falsified. Both SST-I and SST-II were supposed to meet these requirements, though to a different extent. Whereas SST-II was capable of some development, SST-I could only specify the details of its empirical consequences. All the details were in fact potentially present in the original introduction of SST-I. Presumably there was no way to dodge a blow from possible negative evidence.

Whether the particular deductive form of SST-I was directly influenced by Popper's theory or not, the steady-state idea and falsificationism proved to be mutually supporting (see, e.g. Bondi and Kilmister, 1959). Because of this close connection between a scientific theory and metascientific views of rationality, the history of SST, and especially its relation to developing astronomical practice, are methodologically instructive.

9. The Steady-State Theory and Observations

All methods of testing SST imply an examination of very distant objects. If the big bang model is correct, and the universe undergoes a global evolution, its past physical state differs in a radical way from its present one. One can learn about it from radiation emitted by distant objects in the past. This should contain information about the past. According to SST, on the other hand, the past of the universe is basically identical to its present. The mean physical characteristics of its population are not subject to any systematic change. Consequently, an observation of any global evolutionary effect manifested in the systematic change of the inherent properties of objects with their distance from an observer would mean falsification of SST. Let us consider how the testing of SST proceeded.

9.1. The Stebbins–Whitford Effect

The reddening in the spectra of distant elliptical galaxies in excess of the redshift contribution discovered by J. Stebbins and A. Whitford in 1948 was the first reported evidence seemingly contradicting SST. Six years later the 'effect' was shown to be an artifact of improper interpretation of the observation technique (Bondi, Gold and Sciama, 1954).

9.2. The Redshift-Magnitude Test

SST and relativistic models predict a perceptible divergence of the Hubble curves at large redshifts defined by $z = \frac{\lambda_{obs} - \lambda_{em}}{\lambda_{em}} \geq 0.5$. The original Hubble–Humason data covered the region up to $z \approx 0.14$. The horizon of optical astronomy had been extended to about $z \approx 0.3$–0.4 in the late 1950s. Some authors interpreted the new data as favoring the big bang model, rather than SST, but the evidence was very far from conclusive.

Even the discovery of quasars in 1963 could not serve to disprove SST by means of *this* test, for the Hubble diagram for quasars was so scattered that there was no question of drawing a reliable curve through the available points corresponding to the identified quasars.

9.3. Counts of Radiosources

SST predicts a simple relationship, $NS^{\frac{3}{2}} =$ const, where N is a number of sources with apparent luminosity exceeding S.[19] The emergence of radioastronomy made this test decisive in the assault upon SST. As a result of extensive observational work headed by the Cambridge astronomer M. Ryle, data appeared that testified to the increase of concentration and/or intrinsic luminosity of radiosources at great distances and, hence, at earlier epochs (Ryle and Scheuer, 1955). Ryle hastened to announce that these results were incompatible with SST. By this premature announcement, he did SST a great favor, for the data of Ryle and Scheuer were soon multiply compromised by other observers and theoreticians.

The inability of astronomers to produce reliable 'basic statements' in the 1950s obviously raised the stock of SST. None of its potential falsifiers worked. Bondi (1955) made a short excursus into the history of astronomy and drew up a list of errors committed by observers in the past. His conclusion was that the confidence of astronomers in the precision of their results is unfounded and it is in general not so clear whether theory or observational data should give way if a conflict arises between them.

9.4. The origin of elements

The idea of cosmic nucleosynthesis goes back to the classic work of A. Eddington. He maintained that the elements should have been synthesized in stars. However, the estimates of the temperature in the interior of stars available at that time gave values insufficient for the synthesis of heavy elements. An alternative scenario elaborated in the late 1940s by G. Gamow and his colleagues was the primordial nucleosynthesis of all elements from hydrogen at the early stages of the hot big bang, via successive neutron captures and subsequent β-decays. This approach met insuperable difficulties because of the absence of stable nuclei with mass numbers 5 and 8. Elements heavier than helium could therefore not be formed in the hot past of the universe. To account for their existence, a stellar mechanism, by that time sufficiently understood, had to be invoked again. The situation was favorable to SST, for if the elements could appear (and, by the uniformitarian assumption, are continuing to appear) in stars, no hot past of the universe different from its present is needed. The influential 1957 paper by the

[19]This relationship follows from the fact that, according to PCP, the number of sources per unit proper volume must be constant. See, e.g. Bondi and Gold (1948, pp. 260–261); Bondi (1960, pp. 146–147).

Burbidges, Fowler and Hoyle was greatly stimulated by SST, and the latter, in turn, got a second wind.

9.5. Refutation

Real problems for SST started to pile up in the early 1960s. First the discrepancy between different surveys of radiosources had been removed and the conclusive value of the slope of the curve lg*N* vs lg*S* diverging from the prediction of SST by 20% had been firmly established. Then it was shown that stellar processes alone could not account for the considerable amount of helium actually observed in the universe and also for the perceptible presence of deuterium.

Formally, SST can be regarded as having been falsified by these observational data, but only barely so, and not in the spectacular way implied in Popper's model of conjectures and refutations. In fact, both observers and most steady staters (excluding Bondi and Gold) showed no willingness to be good Popperians: the former by their inability to produce definite 'basic statements' capable of killing the 'target', and the latter by their reluctance to serve as a 'sitting target' for the former. Various modifications of SST-II were proposed in the early 1960s to explain away the mounting negative evidence. Retrospectively, they all look manifestly *ad hoc*. Yet SST-II turned into a research program developed in the wake of the big bang theory up to the present, mainly by Hoyle and Narlikar.

Bondi and Gold took the failure of the uniformitarian cosmology at face value. They also seem to have remained true to their methodological principle that a non-uniformitarian 'catastrophic' cosmology cannot be a science. Neither Bondi nor Gold joined the big bang mainstream. Their cosmological activity in fact stopped in the early 1960s.

The final 'death blow' to SST struck by the discovery of the microwave background was, of course, no less a surprise to the steady staters than to the rest of the cosmological community (see, e.g. Bondi, 1982, 1990). It should be emphasized though that, strictly speaking, SST was not *refuted* by this discovery. It is rather that the big bang model was *supported* by it. Contrary to a simplistic falsificationist scenario, theories may go not as a result of refutation, but as a result of their lagging behind their more successful rivals.

10. Conclusions

The methodological battle was lost by the uniformitarian cosmology. As in geology, its 'developmental' rival proved its capacity to be a science. But what happened to the 'interactionist' metaphysics that formed another part of the philosophical foundations of SST-I? It seems it has survived the theory itself and has been tacitly assimilated by the standard cosmology as it made remarkable progress in the last decade.

To save the constancy and uniformity of laws, Bondi and Gold postulated the steady state of the universe. In the modern interplay between cosmology and high energy physics in their joint effort to understand the processes at work during the first moments of cosmic evolution, the problem of 'interaction' arises again, this time in a reversed, dynamical form. Now we have to take the global evolution of the universe at face value and then accommodate properly the entire 'local physics' in the changing conditions of the early universe. Local physics now includes phase transitions breaking the symmetries between the fundamental interactions. Such phase transitions may have occurred in the early history of the universe. More importantly, their occurrence could have been triggered by a cosmological expansion. In this currently accepted picture, the laws of nature (though not the most fundamental ones) turn out to be dependent on the particular state the universe happens to be in as it undergoes its evolutionary development.

Interestingly, no conflict between the non-uniform structure of the universe on a small scale and the uniformity of laws on that scale arises in the modern inflationary scenarios.[20] A symmetry-breaking phase transition occurs in a tiny domain of the early universe. This domain is then inflated into a huge region of the universe governed by the same local laws and comprising the whole observable cosmos as its small part.

The big bang cosmology thus recognized, in its own right, the necessity to take proper account of the influence the physical state of the universe may have on the laws to which it is subject. Along with Milne, Bondi and Gold were among the very few physicists and philosophers who insisted that such a possible influence cannot be ignored if one wishes to think cosmologically.

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[20]Compare it to a similar problem in SST-I discussed earlier on. See Section 4.

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