CORRIDORS OF COSMOLOGY

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Abstract

The course of events that led to the conflict between the two main theories of cosmology in yesteryears, namely, the big bang theory and the steady state theory are recounted. The philosophical positions held by the leading scientists in these events are described. The present status of this debate and the critical role played by the Indian cosmologist J.V. Narlikar in the development of modern cosmology are high-lighted.

1 Encounters

On can say that the 1930s was a period of scientific revolution in cosmology. The paradigm of static universe, which unknowingly influenced even Einstein, fell flat. Its fall was easy since the paradigm itself had no long history and there were not much people who worked on it. Even then, the route to the new big bang paradigm was not unchallenged. In those days, there were more than one paradigm competing with the standard big bang model [2], but this is hardly mentioned in today's textbooks. The reason for this is that, as Thomas Kuhn describes correctly, today's textbooks are written in the new paradigm. In this period of crisis, the paradigm of Friedman, Eddington, Lamaitre and Hubble has engaged in several pitched battles with the alternative paradigms. It was during this crisis that the big bang model could make and implement new weapons and thereby attain a professionalisation which helped it to reach a period of "normal science". For these reasons, the history of cosmology in this period is valuable for curious minds.

Even though most of the people who participated in these controversies were scientists, one can see that they all were very clear about the philosophical overtones of their positions. In those hair-splitting discussions of the 1930s on the philosophy and methodology of science, there were two main camps. In the opinion of one of these camps, formulation of theory involved two closely-linked steps. First, one begins from the empirical observations; i.e., from measurements, observations and experiments, whose results were evident to the human senses. This is classic empiricist epistemology. Observational results would then suggest which are the possible hypotheses to examine, and these would then be examined through further empirical testing. When enough data concerning the hypothesis had been gathered, logical generalization could be carried out, thereby producing a theory. This is classic inductivist logic. Eddington, de Sitter, etc., attempted to build the big bang model along these lines - on the basis of Hubble's observations.

There was an alternative viewpoint to this, a leading figure of which was the famous British astronomer E. A. Milne. In this method of constructing science, one first proposes hypotheses and then by strict logical reasoning make predictions about observations. This is called hypothetico-deductivism. They considered that there are some principles, which the universe must obey. The acceptability of these hypotheses was on the basis of their axiomaticity or simplicity. According to this camp, science is all about testing the predictions of such hypotheses.

The standard big bang cosmology is the logical conclusion of the first approach. The second stream gave birth to the steady state cosmological model, which was popular in later years. The cosmological principle is the fundamental principle in big bang model and the principle says that the universe looks the same, everywhere and in every direction (on a large scale). It was by modifying this principle to the 'perfect cosmological principle' that Herman Bondi, Thomas Gold and Fred Hoyle made the steady state model. This new principle tells that the universe looks the same, not only in every place and direction, but also at all times. One can deduce the steady state model from this principle.

One of the alternative models that appeared soon after Hubble's discovery, and did compete with the big bang model, is the kinematic relativity by Milne. While the big bang model is based on general relativity, the Milne's model was based on special relativity only. Milne was a critic of concepts such as curved space, etc., that appeared in general relativity. His philosophical position, which is often called positivism, did not allow him to endorse the ideas of expanding space, spacetime, etc. He imagined, in his model, that the celestial objects are moving out from the same point, with varying velocities. Even the force of gravity was not taken into account in this model. Milne considered gravity as a force, effective only at relatively small distances. He maintained that the picture we get by considering objects going out with different but constant velocities can be considered a realistic one. This kind of a cosmic scenario is sometimes called a coasting model. It was believed that subsequent observations did not support the model and hence people lost interest in it quite soon. But this enjoys interest as a pedagogical model, even today.

Historically, it was Milne who developed the arguments which led to the concept of a cosmic time, operationally defined with the help of clocks and light signals. He gave only such operational definitions even to concepts like space and time. It was Eddington who first came forward strongly against Milne's views. In his opinion, the concepts of general relativity are not only useful, but also essential. In an article submitted to Nature, Eddington discarded Milne's hypothetico-deductivism and perfect cosmological principle - though many of Milne's operational definitions are used in mainstream cosmology even today. About this, Wittaker has later remarked that the situation that led to Milne's break with a tradition including at least Einstein, de Sitter, Friedmann, LeMaître, Weyl, Eddington, H.P. Robertson and others is to be regretted.

In 1949, Milne was selected as the Chairman of the Royal Astronomical Society, London. In his inaugural address, while mentioning the predictive power of theories, he repeated his position that those theories which are not philosophically satisfactory are not acceptable. However, since after Walker, there were not much research students working with him, the ideas of Milne were soon forgotten.

2 Steady State Model

In 1948, Herman Bondi and Thomas Gold presented the steady state model [1] on the basis of perfect cosmological principle. In Milne's language, it was 'philosophically more satisfactory'. While Bondi and Gold developed its geometry, the same year Fred Hoyle reached at this idea by introducing a new postulate on the matter/energy content in the universe.

Bondi was very well aware of the philosophical overtones of this model. He could appreciate that both schools, the empirical-inductivist school and the opposing hypothetico-deductivist school had their own merits and demerits. He also believed strongly that the theories belonging to the second category should necessarily be tested experimentally or observationally. In such affairs, Bondi has taken seriously the criterion of 'falsifiability' suggested by Karl Popper. This criterion says that every theory in science should be in principle falsifiable, and hence the scientist proposing a theory has to clearly state which observations or outcomes of which experiments will definitely show that his theory is false. Even though the application of falsifiability criterion is difficult in sciences like cosmology where there are limitations for experiments or observations, the main attempt of Bondi and coworkers was to demonstrate that their own theory was in principle falsifiable and hence is a proper candidate as a cosmological theory. Bondi has reiterated his indebtedness to Popper:

'I think the person from whom we had most help on the philosophical side was Popper. His analysis of science encouraged one to be imaginative, and encouraged one to go for something that was very rigid and therefore empirically disprovable.'

All cosmological models are based on physics. We can make a cosmological model on this basis only by assuming that the laws of physics are unchanging in time, just as they are valid at every positions. Given this, it is more logical to assume that the universe itself is in a steady state, looking the same everywhere and at all times. This is the perfect cosmological principle. The proponents of the steady state theory asked how the universe can have a beginning and an end, when we assume that the laws of physics are unchanging. Following Popper, they also argued that this principle is falsifiable and hence satisfies the essential requirements of a good scientific model. "Show me some fossils from an evolving universe, and I'll give up the steady state theory", Bondi once said.

It should be noted that the steady state model is quite different from Einstein's static universe, which neither expands nor contracts. In the steady state picture, the universe is really expanding. Then how can it be steady? The Hubble parameter is a measure of the expansion rate of the universe and in the big bang model, its value changes continuously. Also at $t = 0$, the time of big bang in this model, the value of Hubble parameter is infinity. But to make a steady state model, we have first to assume this value to be a constant. One can understand the basics of steady state model by following a few mathematical steps, starting from this. As can be done in several other models, even though space-time is curved, we can consider space as flat in this model too. But an important factor which makes this model steady is the structure of matter/energy assumed in it. As the universe expands, the distance between objects will certainly increase. When this happens, if new objects are created in the thus newly created space, the universe may look the same at all times; i.e., it may appear steady. Thus a characteristic feature of this model is that it has continuous creation of matter. Then there arises the question whether this kind of continuous creation is observed in nature. But calculations show that there need to be only the creation of one proton or one neutron in a volume of size 1 km^3 and hence none of the experiments or observations we can perform today will be able to detect this. However, one should make it clear at which place this creation takes place - whether it is at the centre of galaxies or in the vast empty spaces (voids) found between galaxies or in galaxy clusters? The famous cosmologist Steven Weinberg [2] accuses that this model is silent on this issue. It is also not known how this process occurs and from where the energy required for this comes. If we do not want the violation of energy conditions, one should assume an unknown field - the creation field - for this purpose. It was Fred Hoyle who worked out the details of this field.

Among other things that can be put to observational tests in this context comes the rate of change of expansion rate itself, which is called the deceleration parameter. This too can be found using the help of observational data, just as one finds the Hubble parameter. Since the expansion rate decreases in the big bang model, the deceleration parameter, as it is defined, is positive. But in the steady state case, this ought to be negative. In fact, there is a clear-cut prediction in that model; the deceleration parameter =-1, which means that the expansion of the universe must be accelerating. The observations till 1998 were generally supportive of the big bang model. But the newly discovered accelerated expansion of the universe supports the steady state model, at least in this aspect.

Strictly speaking, both the above features, i.e., continuous creation of matter and the value of deceleration parameter, were not major obstacles before steady state theory. The cosmologists behind this model had a clear cut reply to those big bang cosmologists who criticise it for the continuous creation of matter: how can one believe in the violent creation of the entire matter in the universe at one instant $t = 0$ and criticise the relatively calm continuous creation? Likewise, everyone knew that there is considerable uncertainty in the measured value of deceleration parameter.

The greatest threat to steady state cosmology, however, came from another corner. This was the cosmic microwave background radiation discovered in 1965. The microwave background radiation can be considered as a ‘fossil’ in a universe which has evolution (such as the big bang model). Since the discovery of such a fossil will naturally lead to the falsification of the steady state model, Herman Bondi, true to his philosophy, declared that he is giving it up.

However, Fred Hoyle, Jayant Narlikar and Chandra Wickramasinghe, who were then working on the steady state model argued that the observed microwave background radiation may have other reasons to exist too. In some studies they have published in 1967, it was found that the kind of iron whiskers (very small grains of iron) that might have been produced in galaxies can absorb star light and re-emit them in microwave wavelengths. They pointed out that the amount of light observed in our own galaxy is of this order. That such iron whiskers can be produced in the high temperature zones around stars was proved experimentally in laboratories on earth itself. Weinberg [2] has opined that this possibility cannot be negated outright. The Hoyle-Narlikar combine often ridicule those who argued that the production of iron whiskers is artificial for the arbitrariness of concepts such as dark energy and dark matter, on which big bang model had to rely lately, without any experimental evidence whatsoever.

In spite of all these, the discovery of the background radiation is really a success story for the big bang, for it was an important prediction in that model. At the same time, the steady state model as such does not predict it. For these reasons most people do like to view this radiation as a relic of a hot early universe, and thus, as a very strong evidence supporting big bang model.

3 Jayant Narlikar

Looking backward, it may seem astonishing that in the growth of quantum mechanics in the first half of the twentieth century, there were major contributions from scientists in India, which was only a British colony at that time. Here are some examples. All the fundamental particles in nature can be divided into two categories, namely Bosons and Fermions. The former, which includes photons, the quanta of light, is named after the Bengali physicist Satyendra Nath Bose. It was he who discovered their collective quantum behaviour. Similarly, Sir C.V. Raman, Meghnad Saha, etc. have made significant contributions to the development of quantum mechanics. But contrary to this, India has no names to project, in the case of general theory of relativity during this period. Even S. Chandrasekhar, who wrote the 'horoscope' of stars, showed interest in general relativity only very lately, in the 1960's. The physics research in India shows this 'quantum leaning', in general. The first theorist who paved the foundations of general relativity in India was Prof. V.V.Narlikar, then a professor of mathematics at the Banaras Hindu University. Most of the general relativists in this country belong to the fold of Prof. V.V.Narlikar. His son, Prof. Jayant Narlikar, later shot to world wide fame for his contributions to the steady state model.

Jayant Narlikar says that his desire to become a mathematician was not deliberately cultivated by his father. Here is an incident that took place while he was a student in standard three: The teacher asked each student what his/her parent is doing. Most of them were children of staff members of Banaras Hindu university. "My father is a professor" was Jayant's reply. "Professor of what?" the teacher again asked, but the child could not answer it. "Your father is a professor of mathematics" the teacher said. Narlikar remembers that the feeling of shame at not knowing the full answer soon gave way to one of elation, as his father is a professor of his best liked subject, which was mathematics.

Even then, he never forgets to acknowledge the ideal conditions he could enjoy in his pursuits. This humble professor attributes his success to the right people he had around him to support him in every matter. When he says that at $t = 0$ he was fortunate to have the right kind of parents, we recognise that the gentle humour in it is aimed at the big bang model!

In the 1960's, when Narlikar joins Fred Hoyle for research in cosmology, the big bang and steady state models were almost equals. But now in the midst of those who believe that the cosmic radiation discovered in 1965 has falsified the steady state model, there are only a few senior cosmologists including Narlikar who do not accept defeat. Among the criticisms they raise against big bang model, the most important is that this model does not provide a deep insight or revelation that triggers thought. The big bang simply follows an empiricist epistemology. The former students of Hoyle, namely Narlikar, Geoffrey Burbidge, Chandra Wickramasinghe etc. have accused that even young researchers in cosmology do not hesitate to join the flock, without evaluating the situation objectively. The witty Burbidge had once qualified themselves as 'old revolutionaries' and the opponents as 'young conservatives' in cosmology!

After obtaining his Ph.D. in 1963, Narlikar started his career as a researcher and a professor in Cambridge and later in some of its allied institutions. At Cambridge, in order to cope with the fast changing situation on the observational and computational front in astronomy, Hoyle was feeling the need to set up an institution where visitors from active centres in the world would visit and discuss their work and thereby positively and constructively influence the working of academics there. When the response from the university and the government was not very forth-coming, private organisations such as Wolfson Foundation, Nuffield Foundation etc. came to support him. Finally when Cambridge University donated the necessary land for construction, Hoyle's dream project named 'Institute of Theoretical Astronomy' materialised. To what will happen to the institute when the Nuffield grant runs out, Hoyle replied that if the institute does not grow to a world class institute by that time, he for one would shed no tears at its abolition!

Narlikar was among the founding faculty in this institute. He got inspiration to start such an institution in India from this experiment. Narlikar opines that whereas institutions are created to boost egos of certain individuals, and continue long past their usefulness because no one has the courage to abolish them, the success of the institute justifies Hoyle's vision that such an institution was needed.

While returning to India in 1972, even though the steady state picture was fading, Narlikar was considered a national hero. Visiting India on an invitation from the

President, he toured to make a series of lectures, delivered in his sharp and transparent style and attracted students and researchers to this new field. From 1972 to 1988 he worked as the Head of Theoretical Astrophysics at the Tata Institute of Fundamental Research (TIFR), Mumbai. This institute has by that time become a world renowned research institute under the able leadership of Homi J. Bhabha. Narlikar has disclosed that Bhabha's insights as to how to run a research institute has helped him a lot.

In 1988, the then University Grants Commission (UGC) chairman Prof. Yash Pal entrusted Narlikar with the task of establishing a world class institution for astronomy, astrophysics and allied subjects. On the outskirts of the Pune University Campus, by the side of the old Mumbai-Pune highway, the space for this was made available. Thus started the beautiful 'Inter-University Centre for Astronomy and Astrophysics' (IUCAA), designed by the world famous architect Charles Corrhea, hardly two kilometers from the Khadki railway station in Pune, which was formerly grasslands and small woods where cattle used to graze. Narlikar was its founder Director. Around a hundred researchers, many of them from abroad, stay and do research here. Many students and teachers from various Indian universities come to visit IUCAA quite often for interactions and references. Previously, any research grants for astronomy and astrophysics were given to individuals and university, college departments, directly by the UGC. But now a good chunk of it is spent through IUCAA.

After being at the helm of action as Director for fifteen years, Narlikar is Professor Emeritus at IUCAA now. The most curious thing is that by this time the paradigm of steady state model is almost wiped out. In 1994, Hoyle, Narlikar and Burbidge have together proposed the quasi-steady state cosmology (QSSC), a modified version of steady state model. In this new model, it is conceived that the universe oscillates, i.e., cycles of expansion and contraction repeats, even when it is in a steady state. We are now in an expanding phase of it. The model will have a hot past, just as in the standard big bang model. Thus it can explain the microwave background and other phenomena, without much difference from that of the big bang theory. Many people now consider it as not much different from standard big bang model, though they are not willing to test any difference with it at the observational front. Now the situation is such that after Shyamal Banerjee and Ram Gopal Vishwakarma, who helped Prof. Narlikar in his research in QSSC left for teaching assignments elsewhere, there are no research students working in this field at IUCAA.

Narlikar and Co., who were very much confident with QSSC, have expressed their annoyance that theories of science are not defeated; instead, they come to an end with the death or aging of their proponents. That the steady state model now provides a fossil that can be used for studies on the methodology of science is really an irony. Narlikar is disgusted by the plight of this branch of science, which is evident from his words. In an interview given to Frontline after his retirement, he said: "When I entered the field of cosmology as a research student in 1960, the subject was open and there were observational possibilities of checking theories. Today one relies on N-body simulations based on speculative initial conditions to assert what is the correct model of the universe. If I were a research student today, cosmology would not attract me."

It would appear deliberate that none who spoke on the occasion of the send-off given to Prof. Narlikar mentioned his contributions to cosmology, and only mentioned his leading role in the establishment of IUCAA. He regrets that many people now use the theories developed by Hoyle and himself in the 1960s, such as negative energy scalar fields, black holes in galactic nuclei, superclusters and voids, oscillating universe which has no singularity, etc., without bothering even to acknowledge. Most are simply believers in big bang cosmology, though it is inconsistent with ground realities - even the measured value of the basic Hubble constant remains controversial. It is opposed to the spirit of science which asks for repeatable experiments to check a theory.

However, the role of Narlikar and coworkers in keeping cosmology a science is beyond mention. Prof. Richard Ellis, from Caltech in USA, says: ".. the reason why most astronomers believe in the big bang model is that it is the simplest picture that is consistent with the data. But it is very important that there are people who are constantly pushing to be provocative to make us question in more detail, whether this is the right picture or not". Echoing similar views, E.P.J. van den Heuvel of the University of Amsterdam says: "It is very important that you have people like Narlikar who are exploring other possibilities. There is a lot that people do not basically understand. And it is now being told that with WMAP there are only a few details to be filled in and then we know everything. It is not like that. I do not believe that."

References

[1] J.V. Narlikar, *Introduction to Cosmology* (Cambridge University press, 1993)

[2] S. Weinberg, *Gravitation and Cosmology* (Cambridge University Press, 1972)