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Current Speculations about the Origin of the Universe

This paper starts with a historical background because our ancients, from various cultures, have speculated about the origin of the universe. How big is the universe, what does it contain? They have talked about extra-terrestrials, perhaps more powerful than us. The Indian concept of *Brahmand* which, literally translated could mean the Cosmic Egg, has the whole universe contained inside that egg. In the Nordic civilisations there was the concept of a World Tree, whose branches and roots carry everything that you see in the universe, that is things observed in the sky or found on land and in the river or sea. We also have philosophical discussions, and one of the most impressive discussions is in the *Nasadiya Sukta* where there are speculations about the origin of the universe, what was there, if at all, before and whether the original 'nothing' means something. Many perceptive and provocative questions have been asked.

There were some semi-empirical notions based on speculative extrapolations of what you observe. One interesting concept was attributed to Philolaus who belonged to the cult of Pythagoreans. This concept involved a Central Fire with the Earth going round it. The Pythagoreans were asked: Where is the Sun in this picture? The Sun was well out of the picture, not even inside the Earth orbit. The critics must have asked, why don't we see the central fire, although we see the Sun. The reply was that you don't see the central fire because there is a Counter-Earth which moves round the central fire in an inner orbit just blocking your view of the central fire. For a while people accepted this explanation; but sure enough questions were asked as

to why we don't see the Counter-Earth in the sky. The defenders of the idea replied that we don't see the Counter-Earth because Greece is facing the other side of the Earth. To verify this claim some people went in ships or on land towards the other side of the Earth. But they could not catch a glimpse of the Counter-Earth, and so the hypothesis ultimately died a natural death.

This experience is characteristic of a wrong hypothesis and is applicable to modern science also, where if your basic hypothesis is wrong then in order to prop it up you need to add some more parameters or assumptions. This kind of propping up should not be indefinite: the process should stop somewhere and the hypothesis should explain a large number of observations. That is the hallmark of science. If that doesn't happen you should be willing to say okay "I am taking a wrong track, let me go back and reexamine my basic postulates and see if I can find an entirely new explanation." That is how science has progressed, sometimes it has taken the wrong turning, come back and then taken the right one.

Having described some of these earlier attempts to understand the universe, let us move a bit forward in time. When you look at the history of science, of mankind's search for the understanding of the universe, you will find that there always has been a temptation to speculate. The human mind wants to know the answer, it asks questions, and wants the answers. And if the answers are not available from a purely rational or factual stand point, then the mind is tempted to invent answers which satisfy it although they may not satisfy all the factual constraints. So sometimes you find poetic imagination or deep philosophical thought, but facts replaced by pure thought do not constitute science.

With the progress of time, facts began to gather. As our observing tools improved, at some stage man had access to the telescope and he could see much further and more clearly. People gradually made bigger and better telescopes, and employed instruments attached to telescopes. As fact gathering improved, older ideas and speculations began to give way to new fact-based theories. However, adapting to new ideas about the universe has not always been easy. Consider the example of a book on popular science called *The System of the Stars* written in 1905 by Agnes Clerke, who was a very good populariser of science, especially astronomy. In this particular book you find a paragraph, which says the following:

The question whether nebulae are external galaxies hardly any longer needs discussion. It has been answered by the progress of research. No competent thinker, with the whole of the available evidence before him, can now, it is safe to say, maintain any single nebula to be a star system of co-ordinate rank with the Milky Way.

Astronomers were wondering at the time, what the nebular patches on the sky represented. Most believed them to be clouds of gas in our Milky Way, a sentiment reflected by Agnes Clerke. A small minority felt that quite a few of these nebulae were galaxies like our own.

However, within two decades after this categorical statement was made, Edwin Hubble demonstrated that those nebulae were in fact distant galaxies and not part of our Milky Way. How did it happen? Because more sophisticated telescopes were available and astronomers could understand those nebulae better.

This kind of mid-course correction is characteristic of science. Some critics think that it is a weakness of science that it says one thing today and another tomorrow. But this is in fact the strength of science, that it is pragmatic enough to revise its statements based on new data.

It was Hubble who laid the foundation stone of modern cosmology, that is the branch of astronomy which studies the present large-scale structure of the universe, and also what it was like in the past, what it will be like in the future. All these discussions from a scientific viewpoint form part of cosmology. What Hubble found was that these distant galaxies, which he had identified very clearly, were not stationary in space but appeared to move away from us. So as we look in different directions all around us, we find galaxies moving away from us. Hubble found a more systematic aspect of this motion, namely that the farther the galaxy is, the faster it is moving. The speed of recession of a galaxy increases in proportion to its distance from us and is known as Hubble's law. Hubble's original observations were repeated many times and extended to more and more remote galaxies, and this law has stood the test of time.

At first sight this result means that we are a very unpopular lot and that all our neighbours are moving away from us. This may give us some dubious kind of a special position in the universe! Fortunately or unfortunately, we cannot claim even this kind of special status in the universe. For, you can work out easily that if you went and sat on another galaxy and looked at the universe you will find the same result,

namely that all other galaxies are moving away from your new location. So this recession is universal, it is not confined to our location.

This result was a very important discovery and cosmologists interpreted it as the 'expanding universe', that is the whole framework of galaxies embedded in space, is expanding so that any two galaxies recede from each other as per Hubble's law. Theoreticians devised several mathematical models using Einstein's general theory of relativity in which these aspects of the expanding universe could be understood very easily. The first person to do this work was the Russian scientist Alexander Friedmann around 1922-24. He sent his work to Einstein for comments. However, Einstein himself believed, as most people did at the time that the universe is static, and so he felt that Friedmann's models, though of mathematical interest could have no connection with physical reality. Therefore he did not reply to Friedmann. However, as I mentioned earlier, in 1929, (within a few years of Friedmann's work) the expanding universe idea became well accepted. This led to a wide acceptance of Friedmann's models. Unfortunately Friedmann had died by then and did not live to see his work being appreciated.

If we take Friedmann models very literally, we can simulate the universe by a balloon with dots marked on it. As the balloon is blown up all dots on the balloon move away from one another. Similarly galaxies are embedded in space which is being blown up and is constantly expanding. Now imagine that you take a movie of such a growing balloon. If you turn the film backwards, that balloon would be seen getting smaller and smaller until at some point it will shrink literally to a point. In other words if you want to know what the universe was like in the past according to Friedmann's model then you come to the conclusion that a very long time back, something like 10 billion years ago, the universe started from a point-like state bursting out with enormous speed, literally infinite! It blew outwards with a 'big bang', if you follow Fred Hoyle's graphic nomenclature, used while describing cosmology in a public lecture on the radio. Although he coined the phrase in a derisory vein, as he didn't believe that such an event really happened, that name stuck and has remained like that for over five decades. So the so-called Big Bang Cosmology had the origin of the universe in a big explosion after which it has been expanding till the present epoch.

The question a scientist would like to ask at this stage is what evidence do you have that the universe indeed began like that. There

were two items of evidence which played a very important role in establishing the Big Bang idea, the evidence suggesting that far back in time the universe was indeed very hot and very dense. George Gamow, a nuclear physicist, and a great populariser of science, had argued that in the very early times the temperature of the universe was very high. Gamow wrote down mathematical equations and from those equations one could see that when the universe was one second old (that means one second had elapsed after the Big Bang) the temperature of the universe was about 10 billion degrees. As it expanded the universe cooled down.

So if one went down to the stage when the age of the universe was about three minutes one would find that it had cooled down to a few tens of million degrees. Now according to Gamow this period when the temperature cooled through this range was very crucial because according to the laws of nuclear physics, during this interval neutrons and protons came close to each other and were fused to make bigger atomic nuclei. So if the universe initially only had neutrons and protons, then as it cooled through this one second to three minute interval, these neutrons and protons would combine to make bigger and bigger atomic nuclei. In this way, Gamow hoped to demonstrate that all chemical elements that we see in our universe, were made within this one second to three minute duration. However, when one tries to prove this conjecture by calculation, one meets only partial success. One can show that starting with hydrogen, one can make deuterium which is heavy hydrogen, tritium which is a still heavier isotope of hydrogen, then one can go on to make helium, both its lighter isotope as well as normal helium, and then more or less one comes to a stop. Why? The answer is that if you start adding more neutrons or protons to helium, or if you fuse two helium nuclei together to make a bigger nucleus, it soon breaks apart. It just doesn't stick together, and that was the reason why Gamow's method could not be pursued all the way to its logical conclusion beyond making helium.

After Gamow, people made more detailed calculations using more precise measurements of nuclear reactions. Today people have come to the conclusion that during this primordial era, something like 23 per cent of the matter in the universe was converted to helium. A very small percent of deuterium is made; but the rest is mostly all hydrogen. When you check this calculation with observations it matches reasonably well and that is one reason why people felt that Big Bang seems to be the right idea. Although it explains the abundance of light

nuclei, it cannot explain how heavier elements like carbon, oxygen, iron, etc. came into existence. This problem was solved by others and there is a comprehensive work by four astrophysicists who are collectively called 'B-square FH' after Margaret and Geoffrey Burbidge, William Fowler and Fred Hoyle. This gang of four went through the whole gamut of nuclear reactions, not in the cosmological context but in the studies of interiors of stars and they found that one can make all these chemical elements inside stars. So people today believe that light nuclei were made in the early hot universe and heavier nuclei were made in stars.

The second line of evidence, which led to a further confirmation of the Big Bang in the minds of most people, related to another property of the hot universe, namely that it had a lot of radiation knocking around. Two young colleagues of Gamow, Ralph Alpher and Robert Herman argued that this radiation which was present in the early stages of the universe subsequently cooled down and should be seen today in the form of a smooth background pervading the cosmos. Such a radiation background is indeed seen today with a temperature of around three degrees absolute, which is minus 270 degrees Celsius. The further prediction which Alpher and Herman had made was that this radiation should have a certain spectrum which is called a 'black body spectrum'. An indirect measurement of a radiation background of around 2.3 degrees absolute had earlier been reported by McKellar in 1941 though Alpher and Herman were unaware of it. In 1965 Arno Penzias and Robert Wilson accidentally detected a radiation background of around 3.5 degrees absolute. The overall spectrum of the background was indeed confirmed to be of black body type by 1990. The prediction of Alpher and Herman that there should be a relic radiation was therefore borne out by observations.

These are the two reasons why people feel very strongly that the universe indeed had a very hot beginning in the form of a big explosion, and it has since been cooling down. Scientists want to go further and probe the era even closer to the Big Bang. I mentioned that a temperature of something like 10 billion degrees existed when the universe was one second old. One can go closer towards the Big Bang and can ask how hot was the universe when it was $1/100$ of a second old, how hot was it when it was $1/1000000$ (one millionth) of a second old, and so on. Mathematics will tell you how hot it was, but the question is how do you check whether this was indeed so. That exercise was started somewhere in the 1970s and is still being done,

and it has brought together two persons whose paths would not normally cross. One of them is a cosmologist and the other a particle physicist. The cosmologist normally looks at the universe on the very large scale whereas the particle physicist tries to understand what is in the heart of the atom, so that he studies matter at smaller and smaller scales. Their zones of work or interest don't normally overlap, but, in the studies of the very early universe, they have come to discover that they have something common: indeed they can't live without each other!

Why has this happened? When the universe was very hot, all the particles in it must have been very energetic, as this is the common characteristic of something hot. Its constituent particles are moving very fast, and when the universe cools down these particles move more and more slowly. Therefore, when the cosmologist investigates the very early stages of the universe, he needs to know how very energetic particles behave. Only particle physicists can provide the answer. The particle physicists theorise about such very energetic particles. For their experiments, they send particles around in accelerators at great speed and make them collide to study how they interact with one another. Such accelerators exist at international facilities like CERN in Europe and Fermilab in the USA. The purpose of this whole exercise is to find what is generally called the Holy Grail of particle physics, the so called Theory Of Everything (TOE). You may have heard this very ambitious phrase. Earlier they used to talk of a Grand Unified Theory, that means a theory in which all the known basic interactions except gravity are combined. In the Theory Of Everything even gravity is also included. So the particle physicist would like to know whether such a theory exists and if so what does it say.

The man made accelerators at CERN or Fermilab, however, have limitations on how energetic particles they can produce: they can go up to energies of about 1000 GeV. It was by studying interactions of particles with energies going upto around 100 GeV, that particle physicists confirmed the electroweak theory of Salam and Weinberg. (In this theory electromagnetic and weak interactions can be unified into one theory called the *electroweak interaction*.) This experimental verification of a theory was thus within the capability of the man-made accelerators. But the next step towards a Grand Unified Theory also includes the third basic interaction which is called the *strong interaction*. How can one test a grand unified theory? The physicist

will tell you that for this purpose you need an accelerator which produces very very high energetic particles. How energetic? Of energy something like 12 orders of magnitude higher than what your present accelerators are capable of! No man-made accelerator, no matter how high a technology you can think of, is going to reach that level in the foreseeable future.

One should not make any categorical statement about future technologies; but at least in the foreseeable future, you don't expect this to happen. So the problem before particle physicists was that their theory could not be tested. If you don't have any experiment to test your theory, it becomes mere speculation. The Big Bang cosmologists came at this stage with the solution that if you go sufficiently close to the Big Bang you have particles moving very fast because the universe is very hot, and so you can test your Grand Unified Theory when the universe was very very young. How young does it have to be? Earlier, when talking about Gamow's work I had mentioned a stage when the universe was one second to three minutes old. In the 1940s, physicists thought that a highly speculative era. The time scale that I am talking about is much shorter. Write 36 zeros after 1 and divide one second by this large number! That is how young the universe had to be.

When the universe was that young it had particles with high enough energies to be able to test the Grand Unified Theory. So particle physicists said that since a real terrestrial accelerator cannot be made let the Big Bang universe serve as one. Just as the particle physicists needed to work with the cosmologists the Big Bang cosmologists, also needed particle physicists because they wanted to know what the physics of the very early universe was like. Today, the situation is that particle physicists have a vested interest in believing that the Big Bang is correct because that is the only way they can test their theories. Likewise, Big Bang cosmologists would like to believe in whatever theories particle physicists have given because that way they can chalk out the early history of the universe. It is in their common interest to believe that both theories are correct and that belief surrounds the enormous quantity of work which is being done today on the very early universe.

I decided to call my talk as 'speculations' because I wanted to emphasise that, like our ancient ancestors, we are back to speculations about the early history of the universe. This is happening every time you open the newspaper wherein somebody from NASA or CERN

tells you this is how the universe was. I wish that the wordings in such pronouncements were not so categorical, that it recognised the fact that people are only speculating, and that those speculations are at best consistent with what we are observing today. In his introductory remarks Rajesh Kochhar told the story of a girl who smelt of fish because, it was claimed, that one of her ancient ancestors had been a fisherman. That claim could be an untestable speculation. Couldn't there be another more tangible cause, namely that she had recently been cooking fish?

The point that I wish to stress here is that some of the present day observations in cosmology could be explained without having to go back to such esoteric times and temperatures. If such an alternative interpretation is possible then one should take it equally seriously. The impression that is created by the Big Bang cosmologists today is that they have got the right answer howsoever speculative it may seem, and nothing else can work. Before I come to an alternative interpretation let me state a few problems which the Big Bang cosmologists believe they can solve with the alliance forged with particle physicists.

One of the questions people like to answer is why the universe is dominated by matter rather than by equal amounts of matter and anti-matter. All of us on the Earth or in the Solar System seem to be made of matter and there is also reasonable evidence that the stars and other constituents of our Galaxy are made of matter. Theoretically, however, another thing called *anti-matter* also exists and if anti-matter and matter come together they would annihilate each other and a lot of radiation would be produced. You can make anti-matter on a small scale in the laboratory, it lasts for a short time and then it meets matter somewhere as it cannot be kept isolated for long and it disappears. You get some particles of anti-matter in cosmic rays which bombard the Earth. So you do see anti-matter but in a very very small amount and the question that cosmologists like to answer is at what stage in the past history of the universe was a decision made that it shall be matter dominated and not anti-matter dominated. This is a fundamental question which Big Bang cosmology has to answer and this is where particle physicists can help to find the answer. These attempts are called 'Baryogenesis' or creation of baryons which are particles of matter.

Then there are other important issues. I had mentioned in the early part of my talk that Einstein believed in a static universe in which

there is no large scale motion of galaxies. However, in 1917 when he was trying to construct such a model he found that within his existing theory, he couldn't. So in order to get the model right he decided to change his theory by adding an extra parameter to it which is called the *cosmological constant*. In simple terms this constant term implies that any two particles will be repelled by a force in proportion to their distance. You may ask the question, why don't we see this effect on the Earth? Why don't we have an apple going up from the Earth rather than falling on the ground? The answer is the force is extremely small on the terrestrial scale and here the gravity of the Earth dominates over it. But if you apply the law to very very long distances, to cosmological distances of the order of several billion light years, then this cosmological constant becomes really important and shows its effect. So Einstein's idea was to have a static universe balanced between this force and gravity. However, when he found that the universe is not static but expanding, he felt that this extra term is not required and therefore he abandoned it.

If you had asked most Big Bang cosmologists ten years ago, whether this term was needed or not, they would have agreed that it was not needed. If you had asked them five years ago they would have said the same thing. However, three years ago the situation changed and today there is a bandwagon saying that there has to be this cosmological constant. Why? Because certain observations connected with the measuring of distances of remote galaxies in which supernovae (that is, exploding stars) are seen, seem to suggest that the universe is expanding faster and faster and that would be possible only if we have the cosmological constant. This takes away the status of the Big Bang as the primordial force sustaining the present expansion of the universe and instead makes the repulsive force arising from the cosmological constant as the prime mover of the universe. Now the more cautious astronomers would say that you are rushing the point, that one should still make sure that the supernovae which you are looking at, from very far back in time because they are very far away for us, are similar to those nearby. So double-checking of observations is needed and drawing the conclusion that the universe is accelerating is probably premature. On theoretical grounds also, there are many questions associated with the idea of a cosmological constant and particle physicists might provide the answers. Anyway these are two examples which suggest how an interaction between particle physicists and cosmologists will be fruitful. There are many other questions

which will come out of this interaction. I am all for having such an interaction; but I would like to stress that here one is matching two speculations and two matching speculations do not constitute absolute fact.

Now I come to an alternative scenario to the Big Bang cosmology. Several questions arise whenever one proposes an alternative cosmology. How can you explain this radiation background without a hot universe or how can you explain light elements? Recall that these are the two examples which made people believe in the Big Bang. In 1993, three of us, Fred Hoyle, Geoffrey Burbidge and I proposed an alternative to Big Bang which we called the 'quasi-steady state cosmology'. In this cosmology the universe expands on a very long term basis, on a time scale of the order of 1000 billion years. It doesn't do so steadily: it has ups and downs, with each up and down, that is a cycle of expansion and contraction lasting for something like 40 to 50 billion years. When you are buying vegetables in the market, if you compare the prices today with prices five years ago you will find that the price has risen. But during any particular year, the prices can go up and down because when there is good seasonal production, you suddenly get a large quantity of the product which drives the prices down. It goes up again in due course. The quasi-steady state cosmology likewise has a long term steady expansion superposed with oscillations. In any once cycle lasting about 40 to 50 billion years new stars are born, they shine and burn out and their radiation remains around. If we include contribution to radiation background from stars of previous such cycles and work out its temperature we find that it matches very closely with the microwave background temperature of 3 degrees absolute. So this is an alternative explanation!

When I said new stars are born and created, in this cosmology the whole universe is not created in one Big Bang: there is no Big Bang at all but there is a creation of matter at the beginning of each cycle and there is an energy reservoir from which this matter is created. Thus the creation process is as per the law of conservation of energy which is a major principle governing physics. On the other hand, we know that this law breaks down in the Big Bang cosmology at the time of the Big Bang. Can we also explain how the light nuclei are formed in the steady state cosmology? Indeed, if we calculate all the helium produced inside stars in the previous cycles we find that the amount matches the present observations very well.

Ultimately in science, the proof of the pudding is in the eating : the proof of any theory would lie in its experimental verification. The conclusion is that at present we have two alternatives. One is the much preferred Big Bang cosmology which has a lot of untestable speculations, the other is the quasi-steady state cosmology in which ideas are less speculative and are testable by observations. For example, creation of matter is happening all the time so you can see it happening even today. There are several photographs of matter being ejected from the nuclei of galaxies in the form of jets and in the Big Bang cosmology it is always a problem to understand how these jets are formed, where they are coming from and so forth. In the context of the quasi-steady state cosmology, this is an example of new matter being created. We have suggested certain tests for checking this alternative hypothesis and we hope that it would be possible to perform these tests. Then, we may be able to decide which of the two theories works, or perhaps whether both of them fail. Hence there is plenty of challenge left in the subject of cosmology. I am making this sales pitch specially for the younger people who might be tempted to take on these challenges and find the answers to some of the outstanding questions that have defied us, the elders!