Cosmic Perspectives on Human Existence

JAYANT V. NARLIKAR

Let me at the outset mention that for me this lecture brings great honour as well as pleasure. My early years were spent in the campus of the Banaras Hindu University and I recall seeing Dr Sarvepalli Radhakrishnan from a distance on several occasions. These included some of his lectures like the Sunday Gita Lecture and also his chats and discussions with my father who, being a well read academic got on well with him. I may confess to feeling overawed by his impressive personality. But even at a single digit age I could not help being impressed by his scholarly demeanour. One occasion that is engraved in my memory was when he had visited our house for a formal dinner party hosted in honour of a visiting commission chaired by him. As the assembled invitees were enjoying a pre-dinner chat, they were surprised to hear Sankaracharya's well known *dash:shloki* which begins thus:

na bhumirn töyam na téjo na vāyuh
na kham naindriyam vānteshām samuhah
anaikāntikatwatsusupteksidhah
tadekovashishtah śivah kevaloham

The recitation coming from a distance on a quiet evening sounded like *Akashvani*, and like many other listeners, Dr Radhakrishnan wondered if the shlokas sung in tuneful and chaste Sanskrit came from some gramophone record. My father clarified that the reciting voices belonged to his two sons who had specially prepared the recital for the occasion. Whereupon Dr Radhakrishnan called us and conveyed his appreciation.

Even in later years when I went to Cambridge the appreciation and encouragement that I received from him went a long way towards making me aspire for greater academic achievements. I recall in particular the occasion when I applied for a J.N. Tata Endowment scholarship to study in Cambridge and Dr Radhakrishnan was kind enough to write to the Endowment Director in support of my application. That may have been why it succeeded despite being late for that year!

These past links explain why I readily accepted Professor Mungekar's invitation to deliver this lecture. The occasion gives me an opportunity to pay my own humble tributes to a great intellectual. Indeed it will be hard to think of anyone who did so much to simplify and amplify Indian philosophy for the Indians besides making it well known to readers from other countries. Nevertheless, having accepted the invitation I began to have cold feet for the following reason.

My topic today concerns human existence and the perspectives offered by science on it. A lot has been written or talked on various aspects of human existence in various philosophies. However, in recent times the rapid growth of science has made it desirable to include its perspectives also. This is what I wish to highlight in my talk; and being a student of cosmology, I cannot help bringing the overall cosmic picture into our present discussion. So the basic question I wish to ask is this: What, if any, cosmic connection relates the presence of man to the universe as we see it today? Of course, scholars have debated this issue in depth as part of philosophy, and to many of you versed in different philosophies, what I have to say may appear shallow compared to the sophistication attained by previous thinkers. Indeed, recalling the analogy of Kalidasa at the beginning of his epic work *Raghuvansham*, I feel like a

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dwarf trying (unsuccessfully) to pick a fruit from its tree, not realizing that it is accessible only to a tall person. So I apologize to this audience in advance should my efforts today disappoint you.

The historical development in our understanding of the universe

To set up the scenario, let us begin with a brief description of the universe in terms of the teachings and ideas of Aristotle which had man as the most important part of creation, residing at the centre of the cosmos. Aristotle had a whole range of ideas on nature, which controlled and guided the intellectuals of the succeeding generations for no less than twenty centuries. This explains why the human ego naturally worked itself into an uncompromising position from where only the geocentric view was acceptable. Thus Copernicus and Galileo had to suffer for proposing the alternative heliocentric theory. The crux of the matter was contained in the following question: Does the Sun go round the Earth as Aristotle believed or does the Earth go round the Sun?

Of course if the universe consisted of only the Earth and the Sun, this question is undecidable. However, we do have a backdrop of distant stars and against this background we can pose the above question. It is interesting to know that as early as the third century BC the Greek thinker, Aristarchus of Samos had argued as follows, basing his argument on the premise that the Earth goes round the Sun in one year. Given this information, within six months we would move the farthest distance away from where we are today. Thus, if we observe a star today and six months later we should notice the maximum change in its direction. By what angle will the star appear to shift? Here Aristarchus overestimated the effect because the estimates of stellar distances he used for calculation, were much lower than actual. The observing techniques in those times were very primitive and so any effect, let alone the enhanced expectation was not seen. This negative result naturally led to a firmer belief in the geocentric theory.

When Galileo was asked by the Inquisition for his proof of the heliocentric theory, he came up with a wrong answer! Quoting the analogy of water spilling out of a moving glass, he argued that the tidal motions of water in the sea resulted from the movement of the Earth. Several decades later, the real reason for the tidal flows was seen to be in the gravitational attraction of the Moon and the Sun. How then do we decide what goes round what? Indeed, astronomers had to wait till the eighteenth and nineteenth centuries to have proofs of Earth's motion through observations of aberration and parallax. Limitations of time do not permit me to describe these observations here. Suffice it to say that the human ego had to finally concede that man is not at the centre of the solar system, nor is his abode, the Earth, fixed in space.

But the human ego did not rest there! Given that the Sun is at the centre of the Solar System, astronomers till the early twentieth century generally believed that the Sun was also at the centre of the Milky Way Galaxy. Indeed, the 1785 map of the Galaxy prepared by William Herschel, the most distinguished astronomer of the time, showed the Sun at its centre. However, by the end of the second decade of the twentieth century, the improved observations with better telescopes, were quite clear in their message: that our Sun is located two thirds of the way to the boundary of the Galaxy, the diameter of the galactic disc being around 100,000 light years. A light year is the distance traveled by light in one year, which amounts to approximately 9.4 thousand billion kilometers. In short, rather than being at the central position of the Galaxy, we are far away from it lying with the stellar proletariat. This was another blow to human self importance! And more was to come.

There was one more instance in which the majority opinion inspired (directly or indirectly) by human ego had assumed that our Galaxy was the only one of its kind seen in the universe. This belief had persisted right up to the twentieth century. There were a few astronomers who tried to argue that some nebulous images suggested that they belonged to galaxies located far away. Thus, instead of belonging to our galaxy, they were outside it and situated very far away. Such claims had been dismissed as out of touch with reality, vide, for example the following quote from a popular astronomy book written by Agnes Clerke in 1904:

> ...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...

Within two decades this confident assertion was proved to be wrong. Our universe is known to contain at least ten billion galaxies like our Milky Way within the observable range of our best telescopes. So here we are living on a tiny planet of a medium star moving in a galaxy of some hundred billion stars, the galaxy being one amongst ten billion others observable within that range. And that range is around ten billion light years. The entire mass made of stars and galaxies may be as high as of a thousand billion billion suns! (1 billion = 1,000,000 000).

Aware of this enormous 'gap' between the man and the universe, the Cambridge astronomer Arthur Stanley Eddington once commented: "...Man in his search for knowledge of the universe is like a potato bug in a potato in a sack lying in the hold of a ship, trying to fathom the nature of the vast sea..."

This quote, coming from one of the greatest astrophysicists and cosmologists of recent times may sound pessimistic. But despite daunting odds against the effort, scientists have insisted on giving it a try. Testifying to the successes achieved in this venture, Albert Einstein once remarked: *The most incomprehensible thing about the universe is that it is comprehensible.* I will return to this statement later in this talk.

Anthropic approaches

The quest in this instance is aided by observations as well as theories, both striving to form a self-consistent framework. However, as we saw, the paradigm tried carries the unstated assumption that man is somehow important to the universe. The approach is still pragmatic in the sense that if something does not fit in the paradigm there is scope for modification. In this spirit, let us look at some examples of the so-called *anthropic* approaches where the fact that man exists is considered important. My approach may seem long-winded but it eventually gets there!

To illustrate it I will start with the question: What makes the Sun shine? This question had been raised by most civilizations who in the early days concluded that the Sun possessed divine power in order to shine so brightly. Temples devoted to the Sun bear testimony to that belief. The progress of science, however, inspired attempts to solve this question within the known scientific framework. Eventually scientists like Eddington constructed solar models in which all the matter which constitutes the mass of the Sun (estimated to be around two billion billion billion tons) is held together in equilibrium between two opposing forces. Of these the Sun's self gravity acted so as to reduce its size while its internal pressures tended to inflate the Sun. The pressure grew inwards along with the temperature of the star. This model led to the conclusion that the core temperature of the Sun may exceed ten million degrees. The question confronting Eddington was: Where does the Sun acquire energy to sustain such a high temperature furnace? Taking clue from the statements of the French Nobel physicist J.J. Perrin, he concluded that at such high temperatures a nuclear fusion reactor converting four nuclei of hydrogen to one of helium will start to function.

This was in the early 1920s and the idea of nuclear fusion was far remote from the physics then in vogue. Still, Einstein's special theory of relativity was sufficiently well established for scientists to understand Eddington's reasoning. This was simple enough: take four hydrogen nuclei, each with a positive electric charge of one unit. In the reactor convert them into a single nucleus of helium with charge two units. The balance charge (two units) will be carried away by some light particles. However, in this whole process the total mass of matter is *reduced* so that by the famous formula $E = MC^2$, some energy will be created. This is the energy that the Sun eventually radiates.

However, when these ideas were put up to nuclear physicists, they would not buy them! The hydrogen nuclei are nothing but the positively charged protons; and since like charges repel one another, how can you bring together four of them into a very close encounter, they asked. Eddington's idea was that at high temperature in the core of the star all particles move fast and hence in some cases at least such close encounters are not unlikely. This reasoning did not convince the nuclear physicists who questioned that those high temperatures are really high enough. In this controversy Eddington stood out as a defiant defender of his idea. In 1926, in the textbook entitled *Internal Constitution of the Stars* he wrote:

> ...We do not argue with the critic who urges that stars are not hot enough for this process. We tell him to go and find a hotter place...

However, in about a decade or so nuclear physics developed to a level where Eddington's ideas could be verified and passed as correct. The typical nucleus contains positively charged protons and electrically neutral neutrons. All of them are subject to strong attraction when they come close enough, that is, at nuclear distances. At close enough distance, this force dominates over the electrostatic repulsion. In 1939, the nuclear physicist Hans Bethe constructed realistic solar models incorporating all these ideas. One can today work out the solar model with high accuracy and can explain the total luminosity of the Sun (the total radiation emitted per second) this way. The calculation also explained how stars of different masses have different luminosities. Such stars using hydrogen fuel are called *Main Sequence Stars.* The longest part of a star's life is spent on the main sequence.

This success led astrophysicists to greater challenges. As and when the Sun exhausts all its core hydrogen, what will it do? The appeal to nuclear physics suggested adding more neutrons and protons to the helium nucleus. However, there was a serious problem. Helium has atomic mass 4 and by adding a proton to it we make a new nucleus of atomic mass 5. Alternatively, by adding another helium nucleus we make a nucleus of atomic mass 8. *In both cases, however, we end up with an unstable nucleus that breaks back into its original parts.*

This problem seemed to prevent what otherwise could have been an admirable explanation of how chemical elements were made in the universe. If stellar cores provide high temperature fusion reactors, the various nuclei could be made in succession there. One should mention at this stage that an alternative scenario for nuclear fusion was offered by George Gamow. He had argued that very high temperature plasma existed in the hot early phase of the big bang cosmology and that could be used for nuclear fusion. But this alternative also failed for nuclei essentially heavier than helium for the same reason. In the period 1-200 seconds the fusion of neutrons and protons to make light nuclei with atomic masses up to 4 worked admirably; but beyond that stage the universe cooled down rapidly and further fusion did not seem possible.

Coming back to stars, a star of solar mass would continue to draw energy from its core nuclear reactor for around 12 billion years. This reactor, as we just saw, fuses hydrogen to make helium. Long though this span is, it is legitimate to ask: What will happen to a star that has no more hydrogen left to fuse into helium? At this stage the star has an inner core made of helium and an outer envelope made of hydrogen. We recall that the temperature of the star is over ten million degrees in the core. This temperature drops down to a few thousand degrees at the outer surface of the envelope. Thus, although there is hydrogen present in the star, it is much too cool to be fused into helium, which is why the energy production in the star eventually comes to a halt.

In the absence of energy coming out from the centre, the core is no longer able to hold out against its inward pull of gravity. While in an energy producing star huge pressures can be sustained, once the energy production is stopped, the pressures remain inadequate to keep the core intact against the gravitational contraction. The core therefore contracts.

In general when a gaseous mass contracts, it tends to heat up. The temperature of the core therefore rises as it shrinks. And as it reaches close to the hundred million mark, a new fusion reaction is ready to be triggered off within it, a reaction which would now generate energy for the star. What would that reaction be?

In the fifties, several physicists were grappling with this problem. The studies of structures of atomic nuclei suggested the prima facie possibility that the fusion process could, in principle, continue towards the building of bigger nuclei by adding more and more neutrons and protons. However, specific quantitative details prevented progress. The difficulty can be imagined from the following analogy.

Suppose you are erecting a boundary wall by placing layers of stones one on top of another. However, beyond a certain height, the wall becomes unstable and all layers collapse. How then do you proceed at all?

The problem with fusion of nuclei was that having made the nuclei of helium, the next step would involve putting together either two nuclei of helium or a combination of a helium and a hydrogen nucleus, or a proton. In either case, the resulting combination was an unstable nucleus which broke back into smaller ones.

The problem was partially solved by arguing that instead of looking for fusion of two nuclei, why not have a fusion of three? (In the stone wall analogy, placing one stone on top of another may not give a stable structure, but intermeshing three stones together may prove successful.) Thus it was suggested that three nuclei of helium may fuse together to provide a stable nucleus, that of carbon.

In fact this possibility had occurred earlier to a number of scientists working in the field. But there came up another difficulty that seemed insurmountable. In a hot gas, fusion of the helium nuclei would take place provided all three of them arrived at the same place at the same time. Since they are moving in random directions, the chance of this occurring would be rather small. In short, the fusion reactor would not be able to function.

This is where Fred Hoyle, an astrophysicist from Cambridge found an ingenuous solution. He suggested that to compensate for the rarity of such a three-body collision, the fusion process must involve a fast going reaction and the most natural way to achieve that was via a *resonant* reaction.

What is a resonant reaction? Resonance is known to us as a phenomenon occurring in sound. When a violinist tunes the strings of the violin to the right tension, it resonates to certain notes. That is, the frequencies of vibration of the strings exactly match the frequencies of vibration of air in the hollow of the instrument. The result is amplification of those notes. This exact matching is called *resonance*.

In a resonant reaction the energy of the three participating nuclei should exactly match the energy of the new carbon nucleus formed. In such a circumstance, the reaction proceeds very fast (just as the sound of the violin note is amplified). Unless such a resonance is present, argued Hoyle, there will not be any significant production of carbon in the star. Or, to put it the other way round, in order for the star to have a continuing source of energy through fusion, and for it to do so by continuing to produce carbon, *it is essential that such a state of resonance exists*.

Armed with this argument, Hoyle, who happened to be visiting Caltech in 1954, asked the nuclear physicists there to verify if such a state of energy existed for the carbon nucleus. He expected this energy to be somewhat *higher* than the energy for a standard nucleus of carbon. In the jargon of nuclear physics, such a nucleus is said to be in an *excited* state. The excited state does not last for long, however, and the nucleus decays to the standard state by releasing the extra energy. This is the energy that the star could draw upon in order to continue shining. And more importantly, the star would continue to produce carbon. Moreover, this new source of energy brings in new pressures which inflate the star, making it bigger and bigger into a giant star. Giant stars like Aldebaran or Betelgeuse are well known in the sky. When the Sun becomes a giant, it will swallow the inner planets of Mercury, Venus and the Earth.

To begin with, the Caltech nuclear physicists were skeptical of this entire chain of arguments. Nevertheless, Ward Whaling and Willy Fowler and others at the Kellogg Radiation Laboratory at Caltech decided to check the apparently outlandish prediction from an astrophysicist. And they did discover that an excited state of the carbon nucleus exists as Hoyle had expected.

Fred Hoyle had another, perhaps stronger motivation for arriving at this remarkable prediction, than just that the star should continue shining even after all hydrogen fuel has been used up. Why was Hoyle so confident of his prediction? The reason why such an excited state of carbon had to exist, according to Hoyle, was that it was only then that a resonant fusion of three helium nuclei to one carbon nucleus could take place. The "resonance" helps in accelerating an otherwise slow process, for otherwise the possibility of three helium nuclei getting together at the same time would be relatively rare. And because of such a reaction the star can keep on shining and go into the giant state while making carbon in its core. Without Hoyle's conjecture coming out to be true, there seemed no way that elements like carbon and oxygen could be made. Carbon and oxygen are essential elements that go to make up the kind of life seen on the Earth. Thus the fact that we humans are around to observe the universe, makes it imperative that the route to making carbon and oxygen must be open!

Anthropic Principle

This example of Fred Hoyle's reasoning was unusual in the sense that the (arguably obvious) requirement that "man should exist" played a key role in deciding a matter relating to atomic nuclei. A few years later several physicists invoked the same condition (that man should exist in the universe) in order to set limits on physical laws and the fundamental constants appearing in them. These arguments go under the name of *Anthropic Principle.* As we shall soon see, this reasoning does not have a predictive power that Hoyle's arguments had.

Consider a 'numerical coincidence' that has been puzzling physicists for a long time. In a short letter published in the famous scientific journal *Nature* in 1937, the Nobel Laureate physicist Paul Dirac drew attention to three very large numbers with no units or dimensions. These numbers come out of combinations of well known physical constants:

(1) The ratio of the electrostatic force of attraction between a proton and an electron (the basic constituents of the Hydrogen atom) to their gravitational attraction, which is of the order of magnitude 10^{40} (forty zeros after one);

(2) The ratio of the radius of the observable universe to the radius of the electron, which is also a large number of this same order; and

(3) The number of hydrogen atoms in the observable universe, which is of the order of 10^{80}, that is around the product of the first two large numbers.

Given that all these numbers are enormously large but comparable in magnitude, the question is, is their occurrence a coincidence or does it carry a deeper significance?

This 'deeper' significance was explained by Brandon Carter and Robert Dicke by introducing the anthropic principle. I can do no better than quote Roger Penrose on how it is done:

> The argument can be used to explain why the conditions happen to be just right for the existence of (intelligent) life on the earth at the present time. For if they were not just right, then we should not have found ourselves to be here now, but somewhere else, at some other appropriate time. This principle was used very effectively by Brandon Carter and Robert Dicke to resolve an issue that had puzzled physicists for a good many years. The issue concerned various striking numerical relations that are observed to hold between the physical constants (the gravitational constant, the mass of the proton, the age of the universe, etc.). A puzzling aspect of this was that some of the relations hold only at the present epoch in the earth's history, so we appear, coincidentally, to be living at a very special time (give or take a few million years!). This was later explained, by Carter and Dicke, by the fact that this epoch coincided with the lifetime of what are called main-sequence stars, such as the sun.

> At any other epoch, so the argument ran, there would be no intelligent life around in order to measure the physical constants in question — so the coincidence had to hold, simply because there would be intelligent life around only at the particular time that the coincidence did hold!
>
> *The Emperor's New Mind, Chapter 10*

In short, if the large constants indicated by Dirac had any other values because the basic constants defining them were different from what they actually are, then there would have been a different solar model. For example, if the gravitational constant were larger than its measured value today, then the Sun would have shone more brightly and would have burnt out much sooner than in the actual case. Thus the presence of the Sun shining brightly today as seen by us humans contradicts that alternative.

Some scientists have argued that there is not one but many universes each with different values of fundamental physical constants. Only in a shortlisted subset (ideally in only one) of those universes would life appear and evolve to the development of the human being. As yet this programme has not succeeded.

The anthropic principle has several versions, some go under the category of 'weak' while some are 'strong' principles. The types and their scopes and limitations have expanded over the years and there is no unanimity as to what should go into the final unique principle. Against this backdrop, the only clear and genuinely predictive application of the anthropic idea was the one used by Hoyle to explain the production of carbon. Hoyle's arguments predicted a new energy level of excited carbon which indeed was found. On the other hand, a typical application in the rest of the cases always involves "postdiction"; that is the anthropic argument is used to *post-facto* justify the values of some physical constants. And even those values are not fine-tuned as Hoyle's for the excited state of carbon,

Some deep questions

I now come to some deeper philosophical issues concerning science. Recalling Einstein's remark that the most incomprehensible thing about the universe is that it is comprehensible, one may paraphrase it thus. The successes achieved by science, modest though they are, show that the science we discover and learn here on the Earth, generally works well in its applications to the cosmic environment. A priori there seems no reason for this to be so. That it does work well makes the scientist's job that much easier. But why? Why should the laws of science we happen to discover in our tiny abode be applicable to the vast universe? Why does Nature indulge the scientists by making things "easy" for them?

The above puzzle becomes even more intractable if we add the query: Why should there be laws of science applying to the universe in the first place? The universe, for example, could be chaotic and governed by no law! So, why are there laws in the first place? And if there are, why do they seem to be valid over very large regions of space and time? I do not think we are likely to get answers to these questions in our lifetime. Moreover, I do not expect the answers to come from within science alone... because they concern science as a whole.

But while one may try to be optimistic on this front, the same Fred Hoyle has left behind a cautionary note. In 1970, at the Vatican Conference on cosmology, where many leading cosmologists were confidently asserting that the big bang origin of the universe was confirmed and that most important questions in cosmology had been answered, Fred had this to say:

> I think it is very unlikely that a creature evolving on this planet, the human being, is likely to possess a brain that is fully capable of understanding physics in its totality. I think this is inherently improbable in the first place, but even if it should be so, it is surely wildly improbable that this situation should just have been reached in the year 1970.

This cautionary remark is scarcely heeded. For example, the cosmological picture of 1970 did not contain such important components as non-baryonic dark matter, dark energy, inflation, etc. These inputs are deemed essential for the cosmological picture today. But we may well ask: Is today's picture final? And the leading cosmologists would reply in the affirmative with the same ring of certainty that their predecessors of 1970 had. If the 1970 picture is now seen to be lacking in several aspects how can we be sure of being correct today? To this question the reply will almost surely be that the present observational support on which today's evidence rests, is far superior to that available in 1970. Of course the cosmologists of 1970 had also the made the same claim!

I personally find myself in tune with J.B.S. Haldane when he said: *The universe is not only queerer than we suppose, it is queerer than what we can suppose.*

Concluding remarks

The topics of origin and purpose of man have been parts of religions and philosophies in the East as well as West. In science also they get discussed now and then as I have indicated here. The scientific point of view leaves open the possibilities that other more advanced species than humans may well exist. If so, the usual motivation of the anthropic principle loses its gloss. For one may then need to define a different set of values for the fundamental constants.

On the other hand, one may set up human existence as a boundary condition to restrict the possible ranges of physical laws. This condition simply shortlists the possibilities without assigning any primary status to man.

The science we study is often referred to as *natural philosophy*. What I talked about today might be considered part of that subject, although I am conscious of being a little-read person in the field highlighted by Dr Radhakrishnan. I do hope, however, that some of the issues raised by me today will attract intellectuals from the traditionally non-scientific fields. I feel that classical philosophers may have a lot to offer in such a discussion with natural philosophers.

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