ASTRONOMY IN SCIENCE AND IN HUMAN CULTURE

JAWAHARLAL NEHRU MEMORIAL LECTURE 1969

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It is hardly necessary for me to say how deeply sensitive, I am to the honour of giving this second lecture in this series founded in the memory of the most illustrious name of independent modern India. As Pandit Jawarharlal Nehru has written, "The roots of an Indian grow deep into the ancient soil; and though the future beckons, the past holds back."

I hope I will be forgiven if I stray for a moment from the announced topic of my lecture to recall, how forty-one years ago, I was one of thousands of students who went to greet young Jawaharlal (as we used to call him at that time) on his arrival to address the National Congress meeting in Madras that year.

I recall also how the dominant feeling in all of us at that time was one of intense pride in the men amongst us and in what they inspired in us. Lokamanya Tilak, Mahatma Gandhi, Lala Lajpat Rai, Motilal Nehru, Jawaharlal Nehru, Sardar Patel, Sarojini Naidu, Rabindranath Tagore, Srinivasa Ramanujan—names that herald the giants that lived amongst us in that pre-dawn era.

The topic I have chosen for this lecture, "Astronomy in Science and in Human Culture," is so large that I am afraid that what I can say on this occasion can at best be a collection of incoherent thoughts. In the first part of the lecture I shall make some general observations on ancient Hindu astronomy, particularly with reference to the way it relates Hindu culture to the other cultures of antiquity. I am not in any sense a student of these matters. My knowledge is solely derived from the writings of a distinguished historian of science, Professor Otto Neugebauer, who has kindly helped me in preparing this part of my lecture.

In the second part of the lecture I shall say something about the particular role of astronomy in expanding the realm of man's curiosity about his environment.

One aspect of astronomy is certain: it is the only science for which we have a continuous record from ancient times to the present. As Abdul-Qasim Said ibn Ahmad wrote in 1068 in a book entitled, "The Categories of Nations": "The category of nations which has cultivated the sciences form an elite and as essential part of the creation of Allah." And he enumerated eight nations as belonging to this class: "The Hindus, the Persians, the Chaldeans, the Hebrews, the Greeks, the Romans, the Egyptians and the Arabs".

Chronologically, the interactions between the leading civilisations of the ancient world are far more complex than this simple enumeration suggests. And a study of these interactions provides us with the most impressive testimony to man's abiding interest in the universe around him.

We know today that Babylonian astronomy reached a scientific level only a century or two before the beginning of Greek astronomy in the fourth century B.C. The development of Hellenistic astronomy, after its early beginnings, to its last perfection by Ptolemy in 140 A.D. is largely unknown. Then about three centuries later Indian astronomy, manifestly influenced by Greek methods, emerged. This last fact raises the question as to the way in which this transmission of information from Greece to India took place. Its answer is made particularly difficult since it implies possible Persian intermediaries. Some centuries later, in the ninth century, Islamic astronomy appears influenced by Hindu as well as Hellenistic sources.

While the Greek astronomy rapidly became dominant in the eastern part of the Muslim world from Egypt to Persia, the methods of Hindu astronomy persisted in Western Europe even as
late as the fifteenth century, as I shall indicate later.

As far as Babylonian astronomy is concerned, we know very little about its earlier phases. But it appears that a mathematical approach to the prediction of lunar and planetary theory was not developed before the fifth century B.C. that is to say barely prior to the corresponding stage of development of Greek astronomy. It is, however, generally agreed that the development of Babylonian astronomy took place independently of the Greeks.

An important distinction between the Babylonian and the Greek methods is this: Babylonian methods are strictly arithmetical in character and are not derived from a geometrical model of planetary motion; the Greek methods, on the other hand, have invariably had a geometric basis. This distinction enables us to identify their influence in Hindu astronomy.

Let me make a few remarks on Greek astronomy as it is relevant to my further discussion.

The earliest Greek model that was devised to account for the appearance of planetary motion is that of Eudoxus in the middle of fourth century B.C. On this model planetary motion was interpreted as a superposition of uniform rotations about certain inclined axes. In spite of many glaring inadequacies, this model had a profound impact on subsequent planetary theory. The culmination of Hellenistic astronomy is, of course, contained in Ptolemy's "Almagest" –perhaps the greatest book on astronomy ever written; and it remained unsurpassed and unsuperceded until the beginning of the modern age of astronomy with Kepler.

Ptolemy's modification of lunar theory is of special importance for the problem of the transmission of Greek astronomy to India. The essentially Greek origin of the Surya Siddhanta which is the classical textbook of Hindu astronomy, cannot be doubted: it is manifested in the terminology, in the units used, and in the computational methods. But Hindu astronomy of the North does not appear to have been influenced by the Ptolemic refinements of the lunar theory; and this appears to be true with planetary theory also. This fact is of importance: a study of Hindu astronomy will give us much needed information on the development of Greek astronomy from Hipparchus in 150 B.C. to Ptolemy in 150 A.D.

In early Hindu astronomy, as summarized by Varaha Mihira in the Pancha Siddhantika, we can distinguish two distinct methods of approach: the trigonometric methods best known through Surya Siddhanta and the arithmetical methods of Babylonian astronomy in the astronomy of the South. The Babylonian influence has come to light only in recent years; and I shall presently refer to its continued active presence in the Tamil tradition of the seventeenth and the eighteenth centuries.

I should perhaps state explicitly here that the fact that Hindu astronomy was deeply influenced by the West does not by any means exclude that it developed independent and original methods. It is known, for example, that in Hindu astronomy the chords of a circle were replaced by the more convenient trigonometric function Sin a—(R sin a).

Before I conclude with some remarks on the simultaneous existence of two distinct astronomical traditions in India I should like to illustrate my general remarks by two specific illustrations which are of some interest.

In 1825 Colonel John Warren, of the East India Company, stationed at Fort St. George, Madras, wrote a book of over 500 quarto pages entitled Kala Sankalita with a Collection of Memoirs on the Various Methods According to Which the Southern Part of India divided Time. In this book, Warren described how he had found a calendar maker in Pondicherry who showed him how to compute a lunar eclipse by means of shells placed on the ground and from tables memorized as he stated "by means of certain artificial words and phrases." Warren narrates that even though his informer did not understand a word of the theories of Hindu astronomy he was nevertheless endowed with a memory sufficient to arrange very distinctly his operations in his mind and on the ground." And Warren's informer illustrated his methods by computing for him the circumstances of the lunar eclipse of May 31–June 1, 1825 with an error of + 4 minutes for the beginning, –23 minutes for the middle, and – 52 minutes for the end. But is it not the degree of accuracy of his result that concerns us here; it is rather the fact that a continuous tradition still survived in 1825, a tradition that can be traced back to the sixth century A.D. with Varaha Mihira, to the third century in the Roman Empire and to the Seleucid cuneiform tablets of the second and the third centuries.

A second instance I should like to mention is an example of the survival of Hindu astronomy in parts of the Western world that were remote from Hellenistic influences during the medieval times. A Latin manuscript has recently been published which contains chronological and astronomical computations for year 1428 for the geographical latitude of Newminster, England. It used methods manifestly related to Surya Siddhanta. Obviously one has to assume Islamic intermediaries for a contact of this kind between England of the fifteenth century and Hindu astronomy.

While Surya Siddhanta manifests Greek

influence, Babylonian influence has recently been established in the post-Vedic and pre-Surya Siddhanta period. For example, in the astronomy of that period, the assumption of a longest day of 18 muhurtas and a shortest day of 12 muhurtas were made. This ratio of 3:2 is hardly possible for India. But it is appropriate for Mesapotamia; and possible doubts about the Babylonian origin of this ratio were removed when the same ratio was actually found in Babylonian texts. In addition, a whole group of other parallels between Babylonian and Indian astronomy have since been established. Thus, the most characteristic feature of Hindu time reckoning—the tithis—occurs in Babylonian lunar theory.

Clearly all these facts must be taken into account in any rational attempt to evaluate the intellectual contacts between ancient India and the Western world. This problem of the foreign contacts is by no means the only, or even the most important, fact that is to be ascertained. One must consider the Dravidic civilisations of the South on par with the history, the language, and the literature of the Aryan component of Indian culture. It is, as Neugebauer has emphasised, this dualism of Tamil and Sanskrit sources that will provide for us, eventually, a deeper insight into the structure of Indian astronomy.

In his book "Rome Beyond Imperial Frontiers". Sir Mortimer Wheeler comes to the conclusion that "the far more extensive contacts with South India have been a blessing to the archeologists" but he adds that "these contacts had no influence on these cultures themselves." Hindu astronomy provides an example to the contrary. Exactly as it is possible to distinguish between commercial contacts which India had through the Punjab or through the Malabar and Coromandal Coast, it is possible to distinguish the astronomy of the Surya Siddhanta on the one hand and the Tamil methods on the other. This distinction is indeed very marked. The Surya Siddhanta is clearly based on pre-Ptolemaic Greek methods while the Tamil methods, in their essentially arithmetical character, manifest the influence of Babylonian astronomy of the Selecuid-Parthian period.

One must not, of course, conclude that the Tamil methods were imported directly from Mesapotamia while the geometric methods came to the North via the Greeks and through, Persian intermediaries. And as I stated earlier, the fact that the Surya Siddhanta appears to have not been influenced by the Ptolemaic refinements, provides an important key to the development of Hellenistic astronomy between the times of Hipparchus and Ptolemy.

A proper assessment of the role of Hindu science in the ancient world has yet to be made. The problem is made more difficult, than is necessary, by the tendency of the majority of publications of Indian scholars to claim priority for Hindu discoveries and to deny foreign influence, as well as the opposite tendency among some European scholars. These tendencies on both sides have been aggravated by the inadequate publication of the original documents: this is indeed the most pressing need. Since no astronomy at an advanced level can exist without actual computations of planetary and lunar ephimerides, it must be the first task of the historian of Hindu astronomy to search for such texts. Such texts are indeed preserved in great numbers, though actually written in very late periods. But the publication of this material is an urgent need in the exploration of oriental astronomy.

Let me conclude this somewhat incoherent account, bearing on the ancient culture of India, by emphasising that its principal interest lies not in the sharing or in the apportioning of credit to one nation or another but rather in the continuing thread of common understanding that has bound
the elite nations of Abul-Qasim ibn Ahmad in man's constant quest to comprehend his environment.

The pursuit of astronomy at the more sophisticated level of modern science, since the time of Galileo and Kepler, is concerned with the same broad questions even though that fact is often observed by the technical details of particular investigations.

Questions that may naturally occur to one often appear to be meaningless in the context of current science. But with the progress of science questions that appear as meaningless to one generation become meaningful to another. It is to
this aspect of the development of astronomy in recent times that I should like to turn my attention now.

The first question that I shall consider concerns the assumption that is implicit in all sciences. Nature is governed by the same set of laws at all places and at all times, i.e. Nature's laws are universal. That the validity of this assumption must be raised and answered in the affirmative was the supreme inspiration which came to Newton as he saw the apple fall. Let me explain.

Galileo had formulated the elementary laws of mechanics governing the motions of bodies as they occur on the earth; and the laws he formulated were based on his studies of the motions of projectiles, of falling bodies, and of pendulums. And Galileo had, of course, confirmed the Copernican doctrine by observing the motions of the satellites of Jupiter with his telescope. But the question whether a set of laws could be formulated which governed equally the motions of all bodies, whether they be of stones thrown on the earth or of planets in their motions about the sun, did not occur to Galileo or his contemporaries. And it was the falling apple that triggered in Newton's mind the following crucial train of thought.

All over the earth objects are attracted towards the center of the earth. How far does this tendency go? Can it reach as far as the moon? Galileo had already shown that a state of uniform motion is as natural as a state of rest and that deviations from uniform motion must imply force. If then the moon were relieved of all forces, it would leave its circular orbit about the earth and go off along the instantaneous tangent to the orbit. Consequently, so argued Newton, if the motion of the moon is due to the attraction of the earth, then what the attraction really does is to draw the motion out of the tangent and into the orbit. As Newton knew the period and the distance of the moon, he could compute how much the moon falls away from the tangent in one second. Comparing this result with the speed of falling bodies, Newton found the ratio of the two speeds to be about 1 to 3600. And as the moon is sixty times farther from the center of the earth than we are, Newton concluded that the attractive force due to the earth decreases as the square of the distance. The question then arose: If the earth can be the centre of such an attractive force, then does a similar force reside in the sun, and is that force in turn responsible for the motions of the planets about the Sun? Newton immediately saw that if one supposed that the Sun had an attractive property similar to the earth, then Kepler's laws of planetary motion become explicable at once. On these grounds, Newton formulated his law of gravitation with lofty grandeur. He stated: "Every particle in the universe attracts every other particle in the universe with a force directly as the product of the masses of the two particles and inversely as the square of their distance apart." Notice that Newton was not content in saying that the Sun attracts the planets according to his law and that the earth also attracts the particles in its neighbourhood in a similar manner. Instead with sweeping generality, he asserted that the property of gravitational attraction must be shared by all matter and that his law has universal validity.

During the eighteenth century, the ramifications of Newton's laws for all manner of details of planetary motions were investigated and explored. But whether the validity of Newton's laws could be extended beyond the solar system was considered doubtful by many. However, in 1803, William Herschel was able to announce from his study of close pairs of stars that in some instances the pairs represented real physical binaries revolving in orbits about each other. Herschel's observations further established that the apparent orbits were ellipses and that Kepler's second law of planetary motion, that equal areas are described in equal times, was also valid. The applicability of Newton's laws of gravitation to the distant starts was thus established. The question whether a uniform set of laws could be formulated for all matter in the universe became at last an established tenet of science. And the first great revolution in scientific thought had been accomplished.

Let me turn next to the second great revolution in
explicit context of astronomy that was accomplished during the middle of the last century.

During the eighteenth century the idealist philosopher Bishop Berkeley claimed that the sun, the moon, and the stars are but so many sensations in our mind and that it would be meaningless to inquire, for example, as to the composition of the stars. And it was an oft-quoted statement of Auguste Compte, a positivist philosopher, influential during the early part of the nineteenth century, that is in the nature of things that we shall never know what the stars are made of. And yet that very question became meaningful and the center of astronomical interest very soon afterwards. Let me tell this story very briefly.

You are familiar with Newton's demonstration of the chapter of white light by allowing sunlight to pass through a small round hole and letting the pencil of light so isolated fall on the face of a prism. The pencil of light was dispersed by the prism into its constituent rainbow colours. In 1802 it occurred to an English physicist, William Wollaston, to substitute the round hole, used by Newton and his successors to admit the light to be examined with the prism, with an elongated crevice (or slit as we would now say) 1/20th of an inch in width. Wollaston noticed that the spectrum thus formed, of light "purified" (as he stated) by the abolition of over-lapping images, was traversed by seven dark lines. These Wollaston took to be the natural boundaries of the various colours. Satisfied with this quasi-explanation, he allowed the subject to drop. The subject was independently taken up in 1814 by the great Munich optician Fraunhofer. In the course of experiments of light, directed towards the perfecting of his achromatic lenses, Fraunhofer, by means of a slit and a telescope, made the surprising discovery that the solar spectrum is crossed not by seven lines but by thousands of obscure streaks. He counted some six hundred and carefully mapped over three hundred of them. Nor did Fraunhofer stop there. He applied the same system of examination to other stars; and he found that the spectra of these stars, while they differ in details from that of the Sun, are similar to it in that they are also traversed by dark lines.

The explanation of these dark lines of Fraunhofer was sought widely and earnestly. But convincing evidence as to their true nature came only in the fall of 1859 when the great German physicist Kirchhoff formulated his laws of radiation. His laws in this context consist of two parts. The first part states that each substance emits radiations characteristic of itself and only of itself. And the second part states that if radiation from a higher temperature traverses a gas at a lower temperature, glowing with its own characteristic radiations, then in the light which is transmitted the characteristic radiations of the glowing gas will appear as dark lines in a bright background. It is clear that in these two propositions we have the basis for a chemical analysis of the atmospheres of the Sun and the stars. By comparisons with the spectral emissions produced by terrestrial substances, Kirchhoff was able to identify the presence of sodium, iron, magnesium, calcium, and a host of other elements in the atmosphere of the Sun. The question which had been considered as meaningless only a few years earlier had acquired meaning. The modern age of astrophysics began with Kirchhoff and continues to the present. And we all know that one of the major contributions to our understanding of the spectra of stars and the physics of stellar atmospheres was made in our own times by Meghnad Saha.

Now I come to a question that man has always put to Nature: Was there a natural beginning to the universe around us? Or to put the question more directly: How did it all begin? All religions and all philosophical systems have felt the need and the urge to answer this question. Indeed, one may say that a theory of the universe, a theory of cosmology, underlies all religions and all myths. And one of the earliest cosmologies, formulated as such, occurs in the Babylonian epic Enuma Elish in the second millenium B.C. The poem opens with a description of the universe as it was in the beginning:

When a sky above had not been mentioned
And the name of firm ground below had
not been thought of

When only primeval Apsu, their begetter,
And Mummu and Ti'amat-she who gave birth to
them all-

Were mingling their waters in one;

When no God whosoever had appeared,
Had been named by name had been determined as to his lot,

Then were Gods formed within them.

Whether the question of the origin of the universe can be answered on rational scientific grounds is not clear. It might be simplest to suppose that in all aspects the astronomical universe has always been. Or, alternatively, following Compte we might even say that it is in the nature of things that we shall never know how or when the universe began. Nevertheless, recent discoveries in astronomy have enabled us for the first time to contemplate rationally the question: Was there a natural beginning to the present order of the astronomical universe? A related question is: If the astronomical universe did have a beginning, then are we entitled to suppose that the laws of Nature have remained unchanged? The two questions are clearly related.

Let me take the second question first. Have the laws of Nature remained the same? Can the universality of Nature's laws implied by Newton in his formulation of the laws of gravitation, be extended to all time in a changing universe?

It is clear that over limited periods of time the laws of Nature can be assumed not to have changed. After all, the motions of planets have been followed accurately over the past three centuries—and less accurately over all historical times–and all we know about planetary motions has been accounted for with great precision with the same Newtonian laws and with the same value for the constant of gravitation. Moreover, the physical properties of the Milky Way system have been studied over most of its extent–and its extent is 30,000 light years. It can be asserted that the laws of atomic physics have not changed measurably during a period of this extent. And on the earth geological strata have been dated for times which go back several hundreds of millions of years. In particular the dating of these strata by the radio-active content of the minerals they contain assumes that the laws of physics have not changed over these long periods. But if during these times the astronomical universe in its broad aspects has not changed appreciably then the assumption that the laws have not changed appreciably during these same periods would appear to be a natural one. The questions that I have formulated, to have meaning, must be predicted on the supposition that there is a time scale on which the universe is changing its aspect. And if such a time scale exists, the first question is: What is it?

That a time scale characteristic of the universe at large exists was first suggested by the discoveries of Hubble in the early twenties. There are two parts to Hubble's discoveries. The first part related to what may be considered as the fundamental unit or constituents of the universe. It emerged unequivocally from Hubble's studies that the fundamental units are the galaxies of which our own Milky Way system is not an untypical one. Galaxies occur in a wide variety of shapes and forms. The majority exhibit extraordinary organization and pattern.

To fix ideas, let me say that a galaxy contains some ten billion or more stars; its dimension can be measured in thousands of light years: our own galaxy has a radius of 30,000 light years. Further the distance between galaxies is about

50 to 100 times their dimensions.

The second part to Hubble's discovery is that beyond the immediate neighbourhood of our own Milky Way system, the galaxies appear to be receding from us with a velocity increasing linearly with the distance. In other words, all the galaxies appear to be running away from us as though, as Eddington once said, "we were the plague spot of the universe". Hubble's law that galaxies recede from us with a velocity proportional to the distance was deduced from an examination of their spectra.

Now suppose that we take Hubble's law literally. Then it follows that a galaxy which is twice as far as another will be receding with a velocity twice that of the nearer one. Accordingly, if we could extrapolate backwards, then both galaxies would have been on top of us at a past epoch. More generally, we may conclude that if Hubble's relation is a strict mathematical one, then all the galaxies constituting the astronomical universe should have been together at a common point at a past calculable epoch. Whether or not we are willing to extrapolate Hubble's law backward in this literal fashion, it is clear that the past epoch calculated in the manner I have indicated does provide a scale of time in which the universe must have changed substantially. Current analysis of the observations suggests that the scale of time
so deduced is about seventy thousand million years.

With the time scale established, the question I stated earlier can be rephrased as follows: Have the laws of Nature been constant over periods as long as say thirty or forty billion years? And, what indeed was the universe like seventy thousand million years ago? These questions cannot be answered without some underlying theory. While there are several competing theories that are presently being considered, I shall base my remarks on the framework provided by Einstein's general theory of relativity. This theory appears to me the most reasonable.

This is clearly not the occasion to digress at this point and describe the content of the theory of relativity. Suffice it to say that it is a natural generalisation of Newton's theory and a more comprehensive one. On Einstein's theory, applied to the astronomical universe in the large, it follows that at each instant the universe can be described by a scale of distance which we may call the radius of the universe. At a given epoch, it measures the farthest distances from which a light signal can reach us. This radius varies with the time. Its currently estimated value is ten thousand million light years. But the most important consequence that follows from the theory is that this radius of the universe was zero at a certain calculable past epoch some seventy thousand million years ago. In other words, the conclusion arrived at by a naive extrapolation backwards of Hubble's law, interpreted literally, is indeed a valid one. That the theory predicts such a singular origin for the universe is surprising; but it has been established rigorously, with great generality, by a young English mathematician, Roger Penroes.

And finally, it is an exact consequence of the theory that the ratio of the wavelengths of an identified line in the light of a distant galaxy to the wavelength of the same source as measured here and now is the same as the ratio of the radius of the universe now and as it was when the light was emitted by the galaxy.

During the past few years, a dozen or more objects have been discovered for which the ratio of the wavelengths I mentioned is about three. Precisely what has been found is the following. In a laboratory source hydrogen emits a line with a wavelength that is about a third of the wavelength of the visible extreme violet light. But this same line emitted by the stellar object in the remote past and arriving here on earth now is actually observed in visible light. The fact that all the identifiable spectral lines in these objects are shifted by a factor of about three, means that the radius of the universe at the time light left these objects was three times smaller and the density was some twenty-seven times greater than they are now. And a careful analysis of the spectrum shows that during this span of time at any rate the laws of atomic physics have not changed to any measurable extent. To have been able to see back in time when the density of the universe was thirty times what it is now is, of course, a considerable advance. But even this ratio is very far from what it would have been if we take the relativistic picture and go further back in time when the radius of the universe was say ten thousand million times smaller, not merely three times or a thousand times smaller. Does it appear that this extrapolation is meaningless and fanciful? But the general theory of relativity gives a theoretical meaning to such a question since a state of affairs attained by such extrapolation is predicted as an initial state for our present universe. In other words, the question is meaningful, and one can reasonably ask: Is there anything we can observe now that can be considered as the residue or the remnant of that initial singular past? But to answer this question we must take the relativistic picture seriously and determine what it has to say about that remote past. Such a determination has been made by Robert Dicke and his associates at Princeton.

Dicke calculated that at the time the radius of the universe was 10^{10} times smaller, the temperature should have been some ten thousand million degrees—in other words a veritable fireball. And as the universe expanded, radiation of this very high temperature, which would have filled the universe at that time, would be reduced. For example, its temperature would have fallen to ten thousand degrees after the first ten million years. As the universe continues to expand beyond this point, the radiation will cool adiabatically, i.e., in the same manner as gas in a chamber will cool if it is suddenly expanded. And Dicke concludes that the radiation from the original fireball must now fill the universe uniformly, but that its temperature must be very low—in fact 3^0 Kelvin, a temperature that is attainable in the laboratory only by liquefying helium. It corresponds to radiation at a temperature of 270^0 of frost. How can we detect this low temperature radiation?

It can be shown that this radiation at 270^0 of frost should have its maximum observable intensity at wavelength in the neighbourhood of

3 millimeters i.e., the radiation must be present in the microwave region. The remarkable fact is that radiation in these wavelengths has been detected; it comes with incredible uniformity from all directions; and they have all the properties that one might, on theoretical grounds, want to attribute to such fossil radiation from the original fireball.

With these discoveries I have described astronomy appears to have justified the curiosity that man has felt about the origin of the universe, from the beginning of time.

As I said at the outset, man's contemplation of the astronomical universe has provided us with the one continuous thread that connects us with antiquity. And might I add now that it has also inspired in him the best.