

PROFESSOR G. C. SEN MEMORIAL
LECTURE

INERTIA AND COSMOLOGY

By

JAYANT V. NARLIKAR

TATA INSTITUTE OF FUNDAMENTAL RESEARCH, BOMBAY 400 005

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Mr. Vice-Chancellor, Ladies and Gentlemen,

I was indeed honoured to receive an invitation from Jadavpur University to deliver the G. C. Sen Memorial Lecture. Arranging a Memorial Lecture is a fitting tribute to an eminent scholar who died in the service of the University, and I am happy to associate myself with this venture.

As a possible subject for my talk I was asked to include the work on cosmology in which I was co-author with Sir Fred Hoyle. Let me confess at the outset that I find it no easy matter to give a popular talk on what is basically a highly technical subject. Nevertheless, I have decided to accept the challenge and make an attempt at giving you some flavour of what is known as the Hoyle-Narlikar theory of gravity and inertia.

Let me begin with a quotation.

"Nature does not begin with elements, as we are obliged to begin with them. It is certainly fortunate for us, that we can, from time to time, turn aside our eyes from the overpowering unity of the All, and allow them to rest on individual details. But we should not omit, ultimately to complete and correct our views by a thorough consideration of the things which for the time being we left out of account."

These are the words of Ernst Mach, philosopher scientist of the last century, taken from his famous book, *The Science of Mechanics*, published in 1893. The idea expressed in these words will form the guiding theme of my lecture today.

Historical Background

It was Galileo Gallilei who first appears to have appreciated the significance of the property of inertia. Inertia implies the tendency of a body to resist any change in its state. Although

we use this word in several different contexts in our daily life, to the mathematical physicist, inertia has a specific meaning—the meaning given to it by Galileo, in the context of dynamics.

Galileo had a long controversy with the scientific-cum-religious establishment of the day. The establishment followed the precepts of the Greek thinker Aristotle. According to Aristotle a body in motion requires a force to push it along. Galileo, on the other hand believed that force was needed not for maintaining a given state of motion but for changing it. In other words, the external force is related not to velocity but to acceleration which is the rate of change of velocity. To produce acceleration, that is to change the velocity of the body it becomes necessary to take account of its inertia. An elephant has bigger inertia than a cat because a larger force is necessary to budge the elephant from its state of rest than that needed to shift the cat.

Galileo was proved to be right in the end, although it was Isaac Newton who gave the precise laws of motion. Newton's second law tells us that the force acting on a given body equals the product of its mass and acceleration. Mass is a quantitative expression of the inertia of the body. An elephant with the mass of five tons has 1000 times as much inertia as a cat of mass five kilograms.

Newton took it for granted that inertia is an intrinsic property of matter, and that the mass of a body would be the same regardless of its environment. In this context recall the standard school question: "What is the difference between mass and weight?" The weight of our elephant would depend on the force with which it is attracted towards the centre of the Earth. The same elephant taken to the Moon would weigh about one sixth of its weight on the Earth. The mass of the elephant, on the other hand would remain the same on the Moon as it is on the Earth.

The successes of the Newtonian system in explaining the dynamics of terrestrial and astronomical phenomena naturally

established the basic postulates of the system. The postulates, however, did not go unchallenged. In fact Newton himself was in difficulties as is seen by the following example.

The Bucket Experiment

The Newtonian laws of motion require measurements of velocities and accelerations, and these measurements are to be made against a frame of reference. Which frame of reference is really implied? I will give you an example to illustrate the problem.

Imagine a stone tied to a string and whirled round in a circle. An observer A at rest at the centre of this circle sees the stone in an accelerated state. The direction of motion of the stone is changing steadily. Mathematical calculation tells us that the acceleration of the stone is directed towards the centre of the circle. From Newton's second law of motion we know that the force acting on the stone must also be directed in the same direction. Indeed it is. The force is the tension in the string attached to the stone and it is directed towards A, the centre of the circle.

While this observer A at the centre of the circle finds everything consistent with Newton's laws, another observer B staying fixed on the stone has a different experience. Since the stone is at rest relative to him, he concludes that the stone has no acceleration. Nevertheless he would notice the tight string and conclude that there is a force of tension pulling the stone towards the centre of the circle. Why does the stone stay fixed in spite of this force? Clearly the observer B cannot reconcile himself to Newton's second law.

The above example illustrates the fact that not all observers are alike in their interpretation of the laws of motion. Newton himself gave the example of the rotating water filled bucket. Newton's experiment is as follows. Imagine a water filled bucket hanging from the ceiling by a rope. In the stationary state

the level of water in the bucket is horizontal. When, however, the rope is given a twist and the bucket is set spinning the water level becomes concave, dipping at the centre and rising at the boundary. The observer A who sees the spinning buckets concludes that this is the result of accelerated motion. The observer B who is at rest relative to the spinning bucket is puzzled as to why the water level has become concave. Again A and B do not seem to have equal status vis-a-vis Newton's laws.

Newton rationalized the situation by postulating the existence of 'absolute space'. Only when measured against the reference frame of the absolute space do Newton's laws of motion have their familiar form. The observer A in each of the two examples described above is at rest in the absolute space. Whenever we talk of an observer like B in each of the above examples, with acceleration relative to the absolute space postulated by Newton, we have to introduce a new element into Newtonian dynamics. For, the Newtonian laws will not hold as they stand, in the rest frame of B. Here Newton introduced the concept of an *inertial force*.

In our example of the stone whirled round at the end of a string we can reinstate Newton's law in the rest frame of the stone by postulating an equal and opposite force which cancels the tension of the string. Such a force is therefore directed in the outward direction, away from the centre of the circle. Commonly known as the *centrifugal force* this postulated force is an example of Newton's inertial forces. It is the same force that accounts for the curvature of the water surface in a rotating bucket.

The Foucault Pendulum

Let me give another example of inertial forces, which is of a different nature from the centrifugal force just described. This example arises in the context of a Foucault pendulum.

An ordinary clock pendulum is constrained to oscillate in a

vertical plane. It takes a fixed period to complete one oscillation. Imagine now that the pendulum is free to oscillate in any vertical plane. In practice this can be achieved if the suspension thread is attached to a joint which can move freely. The French physicist Leon Foucault had set up such a pendulum around 1851. If such a pendulum is set in oscillation in a given vertical plane, it is found that the plane of oscillation gradually shifts around the vertical axis of suspension. The plane of oscillation makes one complete rotation around this axis in a period which depends on the latitude of the place, ranging from one day at the poles to infinity at the equator.

Why should the plane of oscillation of a Foucault pendulum rotate? Again, the question can be answered by postulating inertial forces. Dependence of the rotation period on latitude gives us some hint that the force to be postulated arises from the Earth's rotation. Indeed, if we suppose that the Earth rotates relative to the absolute space we can deduce the type of inertial force needed for preserving the validity of the laws of motion on the surface of the Earth. This force is called the *coriolis force* and is directed in a transverse direction from the axis of rotation.

Foucault's pendulum therefore gives us a means of measuring the Earth's angular velocity of rotation relative to the absolute space. These observations tell us that the period of rotation is one day.

Is this result surprising?

The Local Inertial Frames

The answer, at first seems not so surprising. We learn at an early stage in our life that the Earth revolves round its polar axis in one day. Surely, the Foucault pendulum is merely confirming that result in a more sophisticated way?

Closer examination reveals the real significance of the obser-

vation. We learn of Earth's revolution by observing the rising and setting of stars. The Earth therefore takes one day to revolve around its axis in relation to the background of distant stars. What Foucault pendulum tells us is the period of Earth's revolution round its north-south axis relative to the absolute space.

The equality of the two answers tells us that Newton's postulated absolute space is none other than the background provided by the distant stars.

Before we proceed further with the implications of this result, it is worth mentioning that twenty years after the publication of Newton's famous treatise *Principia*, Bishop Berkeley had criticised Newton's analysis of the bucket experiment, by pointing out that the role of the background had not been fully appreciated. The difference between the rotating and the non-rotating bucket was physically or observationally decided only in relation to the background. Absolute space introduced by Newton was fictitious and there were no independent means of detecting it.

Now we see that Bishop Berkeley was right in the sense that if we do away with the concept of absolute space and concentrate only on the stellar background, we have an operational definition of a reference frame in which Newton's laws of motion hold. Any other observer in uniform motion relative to this reference frame will also find that the laws of motion hold without modification. All such reference frames are called *inertial frames*. If we have observers accelerated relative to any inertial frame then in their rest frames it becomes necessary to postulate inertial forces. We will refer to such frames as *non-inertial frames*. The rest frame on the surface of the Earth is a non-inertial frame.

To decide whether a reference frame is inertial or non-inertial the operational procedure is to examine the motion of the background of distant stars. If the background is accelerated (for

example, rotating) then the frame is non-inertial and *vice-versa*.

What do we mean by 'distant stars'? As the astronomers expanded the range of their observations they first saw beyond the stars in our local solar neighbourhood. Then their vision extended to remote stars in our Milky Way System or the Galaxy. In the third decade of the present century the 'background' receded still further to galaxies lying close to but outside our Galaxy. The modern telescopes take us to the background of galaxies so far that light takes thousands of millions of years to cover the intervening space between them and us.

But the remarkable thing is that the result of the Foucault pendulum experiment is found to be valid within the observational errors: the Earth's revolution period relative to Newton's fictitious absolute space is the same as it is relative to the background of distant galaxies.

Or, to put it differently, the inertial frames in our local neighbourhood are determined by the background of remote matter in the Universe.

Mach's Principle

It was Ernst Mach in the last century who emphasized the point made earlier by Bishop Berkeley, namely that the 'background' is important to any discussion of dynamics. In his text book 'The Science of Mechanics' which I referred to in the beginning of this talk, Mach notes the important result which we just saw with the experiment of the Foucault pendulum. That the local inertial frame is the one in which the distant parts of the Universe are non-rotating was, according to Mach, not an accident but a consequence of some basic natural law.

We may look at Mach's reasoning in the following qualitative way. How do we measure the mass of an object? As seen earlier, the mass is a quantitative measure of inertia and is

determined by measuring the acceleration produced in the body by an external force. But acceleration cannot be measured without a reference frame. Newton's postulate of an absolute space is hardly of any practical use since there is no independent way of identifying it. If, however, we assume that the Newtonian laws are defined in a reference frame in which the distant parts of the universe are non-rotating, then we have a practical prescription of determining the local inertial frame.

It therefore follows that the measurement of inertia depends upon the background. Remove the background and we have no means of knowing what the inertia of a body is. Hence inertia is *not* intrinsic to the body but it also depends on the background of remote matter in the Universe.

This reasoning is known as Mach's principle and so far as Mach was concerned, these ideas remained qualitative. For example, Mach did not specify *in what way* the mass of an object depends on the background. What is the prescription for determining the mass of a given body in a given model Universe? Does mass remain constant in space and time, in a changing Universe? If the mass changes, what are the observable consequences of such a change? Unless questions like these are answered, Mach's principle cannot be dignified by the appellation of a physical theory.

Einstein and Mach's Principle

Albert Einstein was very impressed by Mach's reasoning and his attitude towards Mach, in the early days was that of a disciple towards his mentor. While formulating his general theory of relativity Einstein had hoped to come up with a quantitative version of Mach's principle. In this effort he was not successful.

That general relativity does not reflect the spirit of Mach's principle can be seen in many ways. I will attempt to describe two features in a qualitative manner.

First consider what is meant by the motion of a test particle in an otherwise empty Universe. By a test particle we mean a particle which has no gravitational influence of its own. In Einstein's general relativity such a particle describes what is known as a *geodesic*. A geodesic is a geometrical curve in space and time which is analogous to the Euclidean straight-line. We know that the straight-line between two points A and B on the Euclidean plane is the curve of shortest length. A geodesic connecting A and B in a general space-time with a geometry which may not obey Euclid's axioms, is a curve along which the distance from A to B is *stationary*. By stationarity we mean that if we alter the shape of the curve slightly, the distance measured along it remains unchanged.

Now there are several solutions of Einstein's equations for an empty Universe with geometries that are non-Euclidean. A particle moving along such geodesics has definite trajectories. What do these trajectories mean? According to Mach, a single particle existing in an otherwise empty universe would not have any background against which to move. So complete indeterminacy should prevail in the motion of such a particle. Yet relativity prescribes definite trajectories!

Lest it is thought that an argument based on empty universe is unphysical let us take a look at another feature of relativity.

Mach's principle evolved out of the observation that the actual Universe is seen to be non-rotating in the local inertial frame. Is it possible within the framework of general relativity to have a model universe *not* showing this property? In 1949, in the volume brought out by the Reviews of Modern Physics to celebrate Einstein's 70th birthday, Kurt Gödel (well known for his theorem on the logical incompleteness of arithmetic) contributed an article on the so called *rotating universes*. In this article Gödel constructed a model from Einstein's equations of general relativity which was manifestly *anti-Machian*. That is, in Gödel's universe a local observer using an inertial frame would find the distant parts of the universe rotating.

Gödel's universe has some undesirable properties which make it unphysical. For example, observations show that the light coming from distant galaxies undergoes an increase in wavelength. In Gödel's model this effect is not present. A somewhat peculiar property of Gödel's model is that it has closed timelike lines. This technically worded sentence means in effect that there are observers in Gödel's universe whose future meets their past, that is, they keep meeting themselves in the past and future!

Although Gödel's anti-Machian example could be discounted on these and other grounds, later work by T. V. Ruzmaikina and A. A. Ruzmikin from the U.S.S.R. produced anti-Machian models from general relativity which were free from any unphysical characteristics. Hence, we can argue that because the theory generates such anti-Machian models, Mach's principle does not follow from general relativity.

Einstein was naturally disappointed at such a conclusion and late in his life he began to lose his early regard for Mach's principle. His disillusionment was based largely on the fact that Mach's principle implies a connection between the local and the distant parts of the universe and such a connection cannot be achieved via local field theories. To understand Einstein's criticism of Mach let us now examine the question of local and nonlocal interactions in physics.

Action at a distance vs Fields

Let us take the example of electricity and magnetism. It was Coulomb who enunciated the law of attraction between unlike electric charges or unlike magnetic poles and the law of repulsion between like charges or like poles. The force of attraction or repulsion was conveyed across the intervening space between the charges or poles. Like the Newtonian law of gravitation the Coulomb laws were of the type known as laws of *instantaneous action at a distance*. What conveyed the interactions across long distances instantaneously remained a mystery.

While the Newtonian law worked fairly well the Coulomb laws fell into disrepute. The practical reason for this to happen was that experiments with rapidly moving electrical charges or with rapidly changing electric and magnetic disturbances demonstrated the inadequacy of Coulomb's laws. It was Maxwell's electro-magnetic *field theory* that gave adequate explanations of all observed electromagnetic phenomena.

In Maxwell's theory there is no mystery about how the interactions span vast distances. Take the example of two electric charges A and B. If A is moved it generates an electromagnetic disturbance, or a field, which propagates out from A in all directions with the speed of light. When this disturbance hits B, B begins to move. The effect of A on B is therefore not instantaneous, nor is it conveyed mysteriously. It is the electromagnetic field that is responsible for the transmission of the disturbance from A to B. In the same way B's influence on A is conveyed via the intervening electromagnetic field.

Maxwell's theory was so successful in describing electromagnetic phenomena that it also launched the notion of a field as a fundamental entity in nature. Physicists came to believe that fields and particles together provide a coherent account of what goes on in nature. The Maxwellian approach paved the way for the description of other interactions in physics. Although Einstein's general relativity represents a *tour de force*, his thinking was certainly influenced by Maxwell's field theoretic approach. The belief that field theory provides a correct description of nature in preference to action at a distance was what led Einstein ultimately to reject Mach's ideas.

Other scientists, however, did feel that Mach's principle should somehow be incorporated in physics. Although the influence of distant matter on local matter suggests action at a distance, such may not actually be the case. In fact the work of D. W. Sciama in the 1950s was dictated by the motive of providing a field theoretical description of Mach's principle.

Revival of Action at a Distance

Let me return to the story of development of electromagnetic theory. Although Maxwell's theory established the field theoretic approach as the correct approach, the action at a distance approach was not totally defunct. Distinguished physicists like K. Schwarzschild, H. Tetrode and A. D. Fokker made independent attempts to revive action at a distance.

The primary difficulty in this approach was the inconsistency between the notion of 'instantaneous' action at a distance and the special theory of relativity. Special relativity categorically stated that no physical interaction travels with speed exceeding the speed of light. Instantaneous action at a distance demanded, on the other hand, that such influence should travel with infinite speed. Can one restate action at a distance so that the light barrier is maintained? This was the question that Schwarzschild, Tetrode and Fokker attempted to solve.

In this attempt they met with partial success. They were able to state the concept of action at a distance in a formal mathematical way so that it was no longer inconsistent with special relativity. However, application of the theory in practice was rendered difficult by Newton's third law of motion which states that action and reaction are equal and opposite.

I will illustrate the difficulty with the example of two electric charges A and B separated by a distance of one light-minute. Suppose A is suddenly moved. Action at a distance states that B will begin to feel the effect of A's disturbance one minute *later*, since the effect travels with the speed of light. This action of A on B must be accompanied by a reaction of B on A. This reaction being equal and opposite must travel back from B to A not only in space but also in time. We therefore have the curious circumstance that A feels the effect of B one minute *earlier* than the instant it originated at B!

Such examples of effects travelling backward in time are

very awkward to deal with in practice, since they play havoc with our well established principle of causality which states imply that causes precede effects. Because of such manifestly difficult problems, the action at a distance approach again ceased to make any progress.

During 1945-49, J. A. Wheeler and R. P. Feynman resolved this impasse by demonstrating that provided we live in a well-filled universe, the anti-causal effects of the type described above tend to cancel out. By a well-filled universe we mean a universe which is capable of absorbing all electromagnetic waves emitted anywhere by any source in it. Wheeler and Feynman showed that a static uniformly dense universe does have this property.

The Wheeler-Feynman approach was discussed extensively in the 1960s within the framework of *expanding models* of the universe, by J. E. Hogarth and by Fred Hoyle and myself. In an expanding universe the population of galaxies is seen to be dispersing. The future state of the universe is therefore considerably different from its past state. The notion of a perfectly absorbing universe which Wheeler and Feynman had introduced now split up into two separate criteria: "Does the future (past) half of the universe act as a perfect absorber of all future (past) going signals?" The interesting result that emerged from these investigations was that if the universe was a perfect future absorber but not a perfect past absorber only causal (that is, future going) influences survive.

There are two types of expanding models. In the first type, popularly known as 'big bang models' the universe started with a big explosion a finite time ago. In the second type there was no beginning and the expansion has been a steady and continuous process. None of the standard big bang models turns out to be causally consistent. The steady state model is causally consistent. If therefore we adopt the action at a distance picture we have a powerful probe of cosmology which is far more clear-cut than any astronomical observations could ever provide. Later Hoyle and I showed that similar conclusions hold if we

study the quantum effects of electromagnetism via action at a distance.

Back to Mach's Principle

I took a diversion into the realm of electromagnetic theory to demonstrate that contrary to Einstein's misgivings, the action at a distance approach is consistent with modern physics. What is more, in our example of electromagnetism we saw how the local behaviour, causal or anti-causal, of an electromagnetic system depends upon the large scale structure of the universe. We could term this as Mach's principle in electromagnetic theory. Can we use the knowledge and experience gained in studying electromagnetic theory to guide us towards a mathematical formulation of Mach's principle for inertia?

In 1964, Hoyle and I made such an attempt. Using the same mathematical machinery which had proved useful towards the understanding of action at a distance electromagnetism, we were able to describe how the inertia of a typical particle arises from the individual contributions of all other particles in the Universe. Although it took us several months to arrive at the final answer, by hindsight it now appears that our final answer was a unique one and that it arose in a straightforward manner from the various criteria imposed on the Machian theory.

The resulting theory was not only consistent with Machian philosophy about inertia, but it also yielded a theory of gravitation which was wider in its implications than Einstein's general relativity. Just as Newton's law of gravitation follows as a special case of general relativity, so did general relativity follow as a special case of our formulation.

There were certain other dividends from our approach which were unexpected. For example, both Newton and Einstein assumed that gravitation is an 'attractive' force. The constant of gravitation G is taken to be positive in both theories. In our theory ' G ' is not an assumed constant, but it emerges

as a property of the Universe; and we can deduce that G must be positive.

Another conclusion which emerges from our theory is that the cosmic force of repulsion, the so called λ -force postulated by Einstein in 1917, cannot exist. In general relativity such a force could be accommodated if needed. While a majority of cosmologists do not believe in the existence of the λ -force, observations are ambivalent on this score. This is why a clear-cut prediction of our theory is of interest.

Is G a constant?

At this stage I wish to recall the words of Ernst Mach quoted at the beginning of my talk, and consider them in the light of the gravitation theory proposed by Hoyle and myself. In the remainder of this talk I will refer to this theory as the HN-theory of gravity.

Both the Newtonian and Einsteinian theories of gravity are local in character, in the sense that they relate the local gravitational influence to the local distribution of matter. The HN-theory by contrast cannot be formulated without taking into account the structure of the Universe. In practice such a theory might have been difficult to apply had the solution of each local problem of gravity demanded our knowing what the Universe is like. Fortunately, this is not necessary. Because the HN theory reduces to relativity for *most* practical purposes we do not need to know all the details of cosmology.

I said 'most' not 'all'. As Mach argued, there are problems where the cosmological details cannot be left out. I will describe two such problems.

The first problem relates to G , the constant of gravitation. the strength of the gravitational interaction is measured by this constant. If G were ten times larger than what it is, the Earth would attract us with ten times its present force, thus

making us all ten times heavier. But is G the same at all places and at all times?

According to relativity the answer to this question is 'yes'. In Newtonian gravity G could vary with time but not with space. What about the HN theory? In that theory there is no *prima facie* reason why G should be a constant, either in space or in time. It is determined from the overall properties of the Universe which may evolve and change. Indeed in some model universes of HN theory G does change with time. (The assumption of a cosmological principle ensures that at a given time all parts of the Universe are physically alike. Such an assumption precludes the variation of G with space).

Can this change in G be measured? The predicted rate is extremely small—a few parts in a hundred billion—per year. Improvement in low temperature technology is needed before such a small rate of change can be detected in a laboratory. Judging by the advance of present technology this improvement may not be impossible to achieve.

Barring direct year to year measurements, we may look for long term effects of a possible variation of G . Take for example, the Earth-Moon system. The size of the present orbit of the Moon round the Earth is related to the period of the orbit by a simple formula containing the constant of gravitation G . As G decreases, the gravitational pull of the Earth on the Moon loosens and they begin to move apart from each other. As the orbit size grows the period lengthens. Can we observe the Moon's orbits accurately enough to check whether the above effects do occur?

The use of accurate atomic clocks and the employment of laser technology have made such measurements possible. Van Flandern at the U.S. Naval Observatory has concluded that there *is* some evidence for a slow decrease of G . This conclusion, is however, controversial. Many people have argued that the tidal force between the Earth and the Moon would

produce a similar effect as the decrease of G and so the observations are inconclusive. Here again we may have to wait a little longer for the situation to clarify.

Lastly, there are geophysical and astrophysical effects of the variation of G . The former affect the structure of the Earth and its evolution from a primitive stage while the latter affect the evolution of stars. I will not go into details of these effects here. Three years ago V. Canuto and I demonstrated that the present astrophysical and cosmological observations are not inconsistent with the HN-theory with a steadily decreasing gravitational constant. So far as the Earth is concerned, a slow decrease in G implies that the gravitational force was stronger in the past than now so that the Earth was closer to the Sun. What is more, the Sun also was brighter in the past than it is seen to be now. The Earth's atmosphere must have played a protective role in the past to keep the surface temperature on the Earth within reasonable limits to permit biological evolution. Also if the Earth has been steadily growing in size, its surface crust would have broken up. Is that how the continents formed?

The Redshifts of Quasars

From these 'down-to-Earth' effects let us go over to the esoteric and remote effects of HN-theory which might explain a strange phenomenon in quasars. Quasars are starlike in appearance but are believed to be immensely more powerful than a typical star. In fact a powerful quasar outshines a galaxy containing hundred billion stars!

The important piece of information which decides how powerful a radiator a quasar is, comes from the measurement of its 'redshift'. The redshift is a measure of the fraction by which the wavelengths of certain well known lines in the spectrum of the quasar are found to exceed the wavelengths of similar lines in the spectra of sources produced in the laboratory. For example, in the quasar with the catalogue number 3C9,

the wavelength of Lyman- α line is found to be at about three times the laboratory wavelength of 1216 Å (Å = Angstrom = ten billionth part of a metre). The fractional increase in the wavelength is therefore 2, which is the redshift of the quasar.

According to a well known law first found by E. P. Hubble in 1929, the redshift of a remote object is directly related to its distance. The larger the distance the larger is the redshift. Given the model of an expanding universe, the astronomer can tell the distance of an object like a quasar or a galaxy if its redshift is known. At least, this is what most cosmologists take for granted.

Some observations of quasars and galaxies are however, beginning to threaten this sacrosanct belief. Such observations have come largely from the work of H. Arp. A typical Arp-observation shows quasars of varying and large redshifts close to a galaxy of low redshift. Suppose for example, we find two quasars A and B of redshifts 1 and 2 close to a galaxy C of redshift 0.05. What do we conclude from such data?

If we apply Hubble's law, we have to conclude that the galaxy C is very close by while the quasars A and B are very distant, B being more distant than A. Yet Arp finds A, B and C closely grouped on the sky. Clearly, the apparent closeness of A, B and C must be an optical illusion: we see them close because A and B happen to be located along directions very close to the direction of C.

Now, given a random distribution of quasars on the sky the chance of the above three directions coming very close is rather small. Statisticians tend to reject a hypothesis if the probability of observing the outcome of that hypothesis is small, say less than 1 part in 100. Many of Arp's observed configurations suggest even smaller probabilities than this.

If we take these low probabilities seriously, we have reason to doubt the underlying hypothesis, namely Hubble's law. We

have to argue that in spite of their large redshifts quasars are relatively nearby objects. In my example we have to assume that all three objects, A, B, C are physically near each other.

Before proceeding further let me state that cosmologists have reasonably strong grounds for believing that Hubble's law holds for galaxies. It is the quasars that cause some doubt, which is why the conclusion in this example was that the quasars A and B being near the galaxy C must be at the same distance from us as C is, which in turn is given by Hubble's law *applied to C*.

In spite of Arp's data the majority of astronomers still believe that Hubble's law holds for quasars also and that *all* the quasar-galaxy associations found by Arp are due to chance. Only time and more sophisticated observations will tell if this confidence in Hubble's law is justified.

I belong to the minority who thinks that the present data on quasars are sufficiently disturbing for this conventional Hubble-law based picture. The high redshifts of quasars are not due to their being very far away but are due to some other cause intrinsic to quasar structure. Naturally, any one departing from the conventional picture has to provide a clue to this 'other cause'.

It is here that the HN-theory may be useful. Recently P. K. Das and I argued that if quasars are shot out of active galactic nuclei in gigantic explosions and if they are made of younger matter, then their redshifts will be higher than those of the galaxies from which they were ejected. This conclusion emerges when Mach's principle is applied to newly created matter.

Although our explanation can account for several of the peculiarities observed in the redshifts of quasars, I personally feel that we need more data before we can definitely assert that quasars are made of younger, more recently created matter

than found in the rest of the Universe. The Space Telescope to be launched around 1985 may well supply the much needed information.

Concluding Remarks

With this prognostication I end my talk today. Once again I thank you all, in particular Jadavpur University for giving me an opportunity to talk about a subject in which I have been involved for the last two decades of my life.