Cosmic merry-go-round

Is The Universe Rotating?

J. V. Narlikar

There are faint indications that it is, but more sensitive probes are necessary before we can decide on the question

IT is said that man made a significant advance in surface transport when he discovered the wheel. From the wheels of a bullock cart to the motors which drive our present technology, we see numerous practical uses of rotation. But, apart from these man-made discoveries, rotation forms an intrinsic and vital part of natural phenomena. From the spinning sub-atomic particles to planets and stars we have a wide range of examples of rotation. Indeed, astronomers tell us that even such large systems as galaxies containing a hundred thousand million stars also rotate. And these findings have led to the speculation about the largest system that can be conceived: the Universe. Is the Universe itself rotating?

Before we seek an answer to this question, let us pause and ask what does the question itself mean?

Does the Earth rotate?

Whenever we talk of a rotating body we have a background in mind, against which the rotation is measured. Take the Earth, for example. The ancient Greeks believed that the Earth is fixed and that the rising and setting of stars is explained by the fact that the celestial sphere containing the stars itself revolves round the North-South axis. Of course, a modern schoolboy is taught that it is the Earth that rotates about its North-South axis and completes one rotation in 24 hours against the background of *fixed* stars. Which of the two interpretations is right? Indeed if the argument is based simply on what is considered fixed and what is considered rotating, the issue will never be resolved. The ancient Greek would continue to argue just as vehemently that the Earth is fixed as the modern astronomer would that it is the stars that are fixed.

Fortunately there is a criterion for resolving the issue—a criterion that tells us also about how to measure the rotation of the Universe. For, remember: the Universe by definition includes everything. There is no "outside background" against which we could measure its rotation. Let us see how therefore we can attach a meaning to the phrase "rotating Universe".

The Foucault pendulum

We return to the controversy of the fixed stars and rotating Earth, and consider an experiment first designed by the French physicist Leon Foucault in 1851. The experiment involves a simple pendulum which is free to oscillate in any vertical plane. Now, the bob of a pendulum—if it is pulled to a height above its lowest position and released from rest—would continue to swing to and fro until air friction brings it to a halt. This to and fro motion is caused by the Earth's gravity which acts in a vertical plane. Because of this force the bob is expected to move in the vertical plane in which it was released from rest. In reality the bob of the pendulum does not quite do that! If we let it swing for a long enough time (by minimising air friction through letting it swing in vacuum, say) we find that the vertical plane in which it swings itself rotates slowly from East to West (Fig. 1).

The reason for this apparently odd behaviour of the Foucault pendulum is not difficult to trace if we go back to the fundamentals of dynamics—to the laws of motion propounded by Isaac Newton in 1686-87. Newton's laws relate the acceleration (that is, the rate of change of velocity) of a moving body to the forces acting on the body. However, as Newton himself realised, these laws do not work in arbitrary frames of reference. Newton postulated the so-called "absolute space" as *the* frame of reference in which the motion of the body was to be described, if his laws were to work. If we decide to use another frame of reference we may have to modify the laws of motion. In particular, if we elect to use a frame of reference *rotating* relative to the absolute space, we would have to add fictitious forces, called the *inertial forces* to the already existing external forces on the body.

If we are travelling in a fast car and if the car makes a sudden turn we are thrown in the direction opposite to that of the turn. What invisible force is responsible for throwing us outward? It is the inertial force which

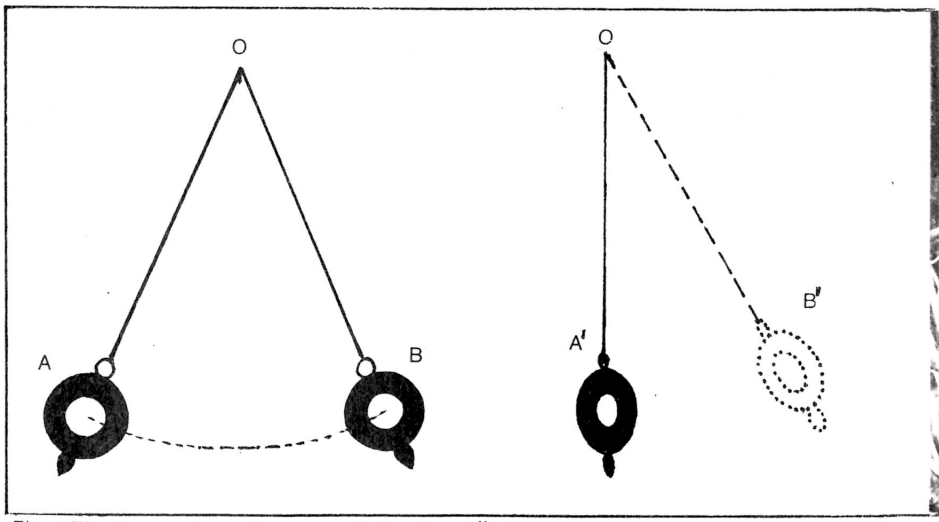
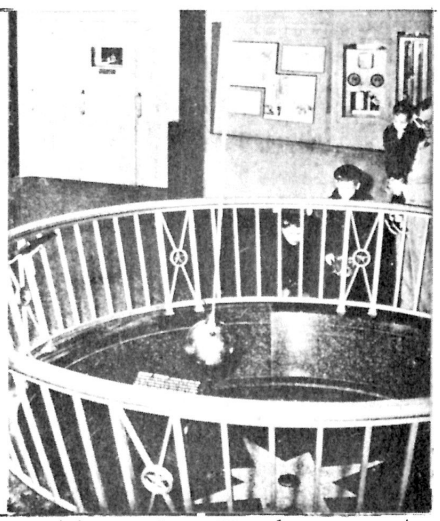


Fig. 1 The Foucault pendulum oscillating in the plane OAB (left). Because of the Earth's rotation, the plane of the pendulum gradually goes round the vertical axis through O and the plane of oscillation rotates to OA'B' (centre). A working model of the Foucault pendulum (right) The original pendulum, 60 m long, was suspended from the roof of the Pantheon in Paris



arises because our frame of reference (that is that of the car) is accelerated relative to the absolute space.

The ancient controversy resolved

The odd behaviour of the Foucault pendulum is explained if we assume that its frame of reference (that is, that fixed on the Earth) is rotating relative to absolute space. The inertial forces arising from the use of this rotating frame of reference make the plane of oscillation slowly rotate from East to West. The rate of rotation depends on the latitude of the place, it being zero at the equator and maximum at the poles. And from these measurements we deduce that the Earth as a whole is rotating about its polar axis from West to East at the rate of nearly one rotation in 24 hours. This rotation is relative to Newton's absolute space.

So, if the absolute space is the background against which rotation is to be measured then the ancient Greeks were wrong: the Earth *is* rotating and the distant stars are at rest.

Well, almost. Careful astronomical observations over several decades have shown that the stars are not exactly at rest relative to the absolute space, either. The stars in our Galaxy are slowly changing their directions in such a way as to imply that the Galaxy as a unit is rotating about an axis. The rate of rotation is quite slow—one rotation taking about 200 million years!

However, we now have a criterion to decide whether the Universe is rotating or not. The method is to look way beyond the stars of our Galaxy, to the vast world of galaxies themselves, and to see if the background of remote galaxies is at rest relative to the absolute space of Newton. If it is, then the Universe is non-rotating.

The Expanding Universe

This world of galaxies was discovered by astronomers in the 1920's and towards the end of that decade came Edwin Hubble's remarkable discovery of nebular redshift. In simple terms, Hubble's discovery implied that the remote galaxies are all moving away from us. This motion is radially away from us—it is not of the transverse type that would imply a rotation of the Universe.

During the early 1920's, G. A. Friedmann had already constructed simple mathematical models of the so-called "Expanding Universe" based on Einstein's general theory of relativity. These models turned out to be successful in describing Hubble's observations, and essentially laid the foundations on which modern cosmology is based.

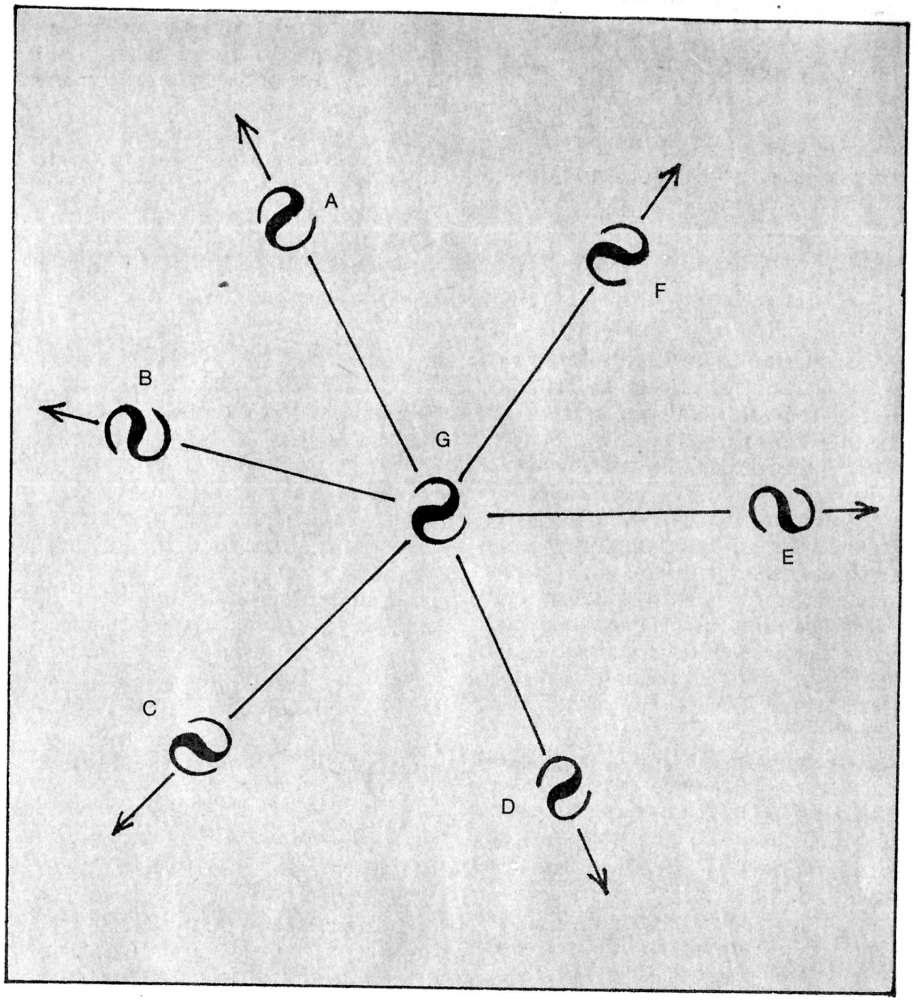


Fig. 2. The distant galaxies A, B,.....F as seen from our galaxy G are moving radially away. A rotating universe would require systematic transverse motions round a preferred direction. Such transverse motions have not been detected

The Friedmann models describe a non-rotating Universe. In the Friedmann Universe the background of distant galaxies is at rest relative to the absolute space. Thus, apparently, we have a satisfactory agreement between theory and observations. Observations do not seem to show any rotation of the background of distant galaxies and the theory is able to account for them with the help of a mathematical model. (Fig. 2).

Mach's principle

The observation that the remote parts of the Universe are non-rotating relative to the absolute space is something of a mystery. The philosopher-scientist Ernst Mach (1836-1916) turned the mystery into something more tangible. Mach argued that all along Newton's absolute space has been no more than an abstract and *ad hoc* concept, and that the correct way of handling the laws of motion is to state them against the background of remote objects. In other words, it is the remote parts of the Universe which determine the local absolute space. Mach further argued that his reasoning also implied that inertia of a body, which is measured by its mass, is determined by the remote parts of the Universe. These ideas, which were never quantified by Mach, are known as Mach's principle.

From our discussion so far it is clear that a non-rotating Universe forms the basis of Mach's principle. And, since the simplest models of the Universe turned out to be non-rotating, this result led Einstein to hope that his general theory of relativity incorporated Mach's principle, albeit in an indirect way.

This hope of Einstein's was belied ironically enough on his 70th birthday! For, in 1949, in a scientific volume dedicated to him on this birthday, among the numerous articles by distinguished scientists was one by Kurt Gödel which explicitly showed that general relativity did not incorporate Mach's principle. (It was the same Gödel who in 1931 had proved the remarkable result that the system of postulates in arithmetic is incomplete. This result, known as Gödel's theorem, is of fundamental significance to foundations of mathematics.)

Gödel's Universe

What Gödel did was to produce a model of a rotating Universe out of Einstein's equations of general relativity. As a model of the actual Universe, the Gödel Universe is hardly satisfactory. It does not show Hubble's redshift phenomenon. What is more, it has 'closed time-like lines' which means that it is possible for a class of observers to meet themselves in the past! Further, it makes use of the λ-term , a cosmic force of repulsion first introduced by Einstein but subsequently considered to be non-existent by most cosmologists including Einstein.

Nevertheless Gödel's model was a mathematical counter-example which opened the way for many more to come. Thus later workers were able to construct models of rotating universes free from the above defects of Gödel's model. And it is now clear that general relativity does not incorporate Mach's principle.

Does rotation prevent singularity?

Apart from Mach's principle, there is another aspect in which the rotating models have generated considerable excitement. The non-rotating models of Friedmann suffer from one defect. They have the Universe originating in a big bang. The big bang represents a singular epoch before which nothing (not even space and time) existed, an epoch at which the geometrical properties of space and time broke down and no physical description of any sort was possible. This singularity is worse than any mathematical or physical difficulty encountered in other branches of science before. Naturally, theoreticians wanted to know whether such a situation could be avoided.

In 1955, the Indian relativist, Amal Kumar Raychaudhuri, derived a result, now well known as the Raychaudhuri equation. Raychaudhuri showed that if the Universe has rotation, then its dynamical properties are different from those of the Friedmann universes. In particular, the additional terms introduced by rotation seem to help in preventing the singularity. Unfortunately, Raychaudhuri's equation did not explicitly say whether singularity *is* prevented. Indeed, as Raychaudhuri pointed out, a rotating Universe also has another property called 'shear' and the shear terms *help* the incidence of singularity. So the tantalising question remained: which of these two opposing trends would win out?

One way to decide this question was to construct explicit solutions of Einstein's equations with rotation and shear to show that the singularity is prevented. Otto Heckmann and Engelbert Schücking who strongly believed that rotation does prevent singularity (a belief generated by their working with Newtonian gravity) worked in this direction, but without success. Only in the late 1960's, with the work of Roger Penrose and Stephen Hawking, did it become clear that singularity is a salient feature of relativity — a feature which cannot be removed by such devices as rotation. With this result the main theoretical attraction of rotating models has gone.

Astronomical observations

Nevertheless we, as observers, can still ask this question: "Is the Universe rotating?" We have already seen how slowly galaxies can rotate. Can we not expect the Universe to rotate even more slowly— completing one rotation in, say, ten thousand million years? For, this is the characteristic time-scale to emerge from cosmological observations. A rotation rate so slow would be very difficult to measure directly; but can we detect its effect indirectly? I end this article with a discussion of two such effects.

An indirect consequence of rotation is anisotropy. The distribution of matter in the Universe is expected to show a dependence on direction with respect to the direction of rotation. Thus, differences with respect to direction should show up in the distribution of galaxies, radio sources, etc. Have such differences been found? At the time of writing there *are* a few such effects which show that the matter distribution in our local neighbourhood is not isotropic. For example, the Rubin-Ford effect tells us that the Hubble law relating the speed of recession of a galaxy to its distance from us is anisotropic. There is also some indication from the radio surveys that the counts of sources are not quite isotropic. However, such effects, even if conclusively established, do not *prove* that the Universe must rotate. These effects could also be explained by postulating local inhomogeneities like superclustering of galaxies.

Anisotropy has also been detected in the background radiation in microwaves which pervades the Universe the bulk of the effect is however due to the fact that the Earth is moving around the Sun, which itself is going around the Galaxy which in turn may have motions of its own relative to distant galaxies. After eliminating this source of anisotropy, a small effect still remains. This small anisotropy which has *not* been conclusively established today suggests that the Universe is rotating.

Finally, laser technology has opened up the promising prospect of measuring the Earth's rotation relative to the absolute space much more accurately than what is possible with a mechanical device like the Foucault pendulum. At the 9th International Conference on General Relativity and Gravitation held at Jena, M. P. Haugan, M. O. Scully and M. S. Zubairy from the Optical Sciences Center of the University of Arizona presented an experimental scheme which is expected to achieve a sensitivity of one part in ten thousand million of the Earth's rotation rate. The scheme uses a device known as ring interferometer with an argon laser.

Such accurate laboratory experiments coupled with the much more sensitive probes of the remote parts of the Universe promised by the Space Telescope to be launched by NASA in 1983 will be needed before we can assert confidently whether the Universe is rotating or not.

Prof. Narlikar is with the Astrophysics Group at the Tata Institute of Fundamental Research, Bombay. He obtained his B Sc from Banaras Hindu University and Ph D and D Sc from Cambridge University. He is a fellow of the Indian Academy of Sciences, the Indian National Science Academy, and the Royal Astronomical Society. His research interests include theoretical physics, gravitation, cosmology, and astrophysics.

Recommends reading: F. Hoyle and J. V. Narlikar, *The Physics-Astronomy Frontiers,* W. H. Freeman, San Francisco,(1980).