Abbe' Georges Lemaître: Father of the primeval atom

J. V. Narlikar

Inter-University Centre for Astronomy and Astrophysics, Post Bag 4, Ganeshkhind, Pune 411 007, India

THE name 'Big Bang' so fashionable in modern times was coined by Fred Hoyle during his public lectures on cosmology in the 1940s. Ironically, Hoyle was not the originator of the big bang model of the universe; rather he was and continues to be a firm opponent. The idea of a universe exploding into existence and expanding as an aftermath of the primeval explosion had originated two decades earlier. Georges Lemaître (1894–1966) was one of the creators of this concept. In this centenary year of Lemaître, when cosmology is going through a period of great excitement it is worth taking a look at those early days 60–70 years ago when the subject was passing through a phase no less exciting. And Lemaître was one of the major contributors to that excitement.

The early days

Born in Charleroi, Belgium, Georges Lemaître was known from his student days as a brilliant mathematician. But his inclination was towards applied aspects of the subject. In September 1910 he joined the Jesuit school in Brussels and a year later passed the entrance test for the College of Engineering in Louvain. But World War I intervened before he could get his degree in engineering. He joined the army and was decorated for service with the *Croix de Guerre* medal. After the war he rejoined the University of Louvain but changed his field to maths and physics, ending with a distinguished Ph D in 1920. Thus he was set for a career in teaching and research.

However, he had another mission in life. He wanted to become a priest and to achieve that goal he entered Maison Saint Rombaut and was ordained in 1923. But by this time he had also mastered the newly developed general theory of relativity which not many scientists in those early days were really at home with. And among those few who were the name of Eddington stood out like a beacon. Lemaître went to Cambridge to work with Eddington with a Belgian Government Scholarship. Eddington was quick to appreciate this gifted colleague and the Eddington–Lemaître combination was to prove a formidable one in cosmology in the years to come.

In 1924 Lemaître visited the Harvard College Observatory and here he received the observational input that was to inspire him towards his own research. In particular, a lecture by Edwin Hubble that he attended gave him the inkling of the way observational cosmology was shaping. Hubble was to publish his epoch-making paper on the nebular redshift-distance relation in 1929; but already in 1927 Lemaître had figured out a cosmological model that would accommodate those observations.

First work in cosmology

His American trip gave Lemaître the right observational input to set him thinking on the cosmological problem. Can one describe the observed large scale features of the universe by simplified solution of Einstein's equations of general relativity as given by him in 1917? With his mathematical skills and observational insight Lemaître was able to crack the problem. In 1927 he published his work (in French) in the Belgian journal *Annales de la Societe Scientifique de Bruxelles* [XLVII A, 49]. He showed his results to Einstein at the 1927 Solvay Congress but the great man was either not impressed or not interested.

There was a reason. Back in 1917 Einstein had proposed a static model of the universe and he still

Figure 1. Abbe' Georges Lemaître (1894–1966).

believed that on the large scale the universe must be static. Hubble's 1929 results demolished that prejudice. If nebular redshifts were interpreted as Doppler shifts then the universe was a dynamic system with galaxies flying apart from one another. How to fit it into a realistic framework within the theory of relativity? The only other solution known generally was that of W. de Sitter, also of 1917, which showed such motion but the universe had to be empty. In the meeting of the Royal Astronomical Society held on 10 January 1930, Eddington expressed the impasse in these words: '*... One puzzling question is why there should be only two solutions ... Solution A (the Einstein Universe) is such a static solution. Solution B (the de Sitter solution) is, on the contrary, non-static and expanding, but as there isn't any matter in it that does not matter*'.

The proceedings of the RAS meeting were published in the *Observatory* (Feb. 1930) and came to Lemaître's notice. He wrote to Eddington gently reminding him of his 1927 paper wherein he had obtained exactly such solutions whose absence Eddington had commented on. Eddington realized that he had indeed forgotten the work by his former student! In the May 9 meeting of the RAS the same year, Eddington paid glowing tributes to Lemaître's model (*Observatory*, June 1930). To further rectify the situation he wrote a brief note about Lemaître's work in *Nature* (June 7, 1930) and also arranged to have the English translation of Lemaître's 1927 article published in the *Monthly Notices of the Royal Astronomical Society* (1931, **91**, 483). The translated title of the paper was: *A homogeneous universe of constant mass and increasing radius accounting for the radial velocity of extragalactic nebulae.* Thus Lemaître's original contribution got recognized. (My father, V. V. Narlikar, who was a student of Eddington during 1930–32 used to recall that he had also obtained solutions similar to Lemaître's and Eddington was about to communicate the work for publication when he became aware of Lemaître's work and so VVN's work was not published.)

Three pioneering theorists

Even before Lemaître another author had published similar work. This was Alexander Friedmann from St Petersburgh in Russia who had published two papers in 1922 and 1924 in the German journal *Zeitschrift für Physik* [**x**, 377 & **xxi**, 326]. Friedmann also had shown his work to Einstein who again did not take them seriously because of the prevailing belief in the 1920s that the universe is static. In Friedmann's case it took ten years for his work to be recognized. Thus when Lemaître wrote his paper he too was unaware of this work.

From today's vantage point credit for the expanding world models is given to Friedmann, Lemaître and H. P. Robertson whose paper also independently appeared in the journal *Philosophical Magazine* in 1928 [7, v, 835]. There were differences in the way each author stressed his basic assumptions; but they all had essentially obtained homogeneous and isotropic models of an expanding universe. For example, Friedmann considered open as well as closed models, i.e. with the curvature parameter $k = 1$, 0 and -1. Lemaître considered the $k = 1$ case but included both matter in the form of dust and radiation in his field equations whereas the earlier author had discussed the dust case only.

The cosmological constant

The 1930s saw cosmology develop along two parallel fronts. On the observational front Hubble continued his programme of extending the redshift-distance relation to farther samples of galaxies, and also initiated attempts to measure the curvature of space through the number counts of nebulae. On the theoretical front Lemaître and Eddington explored the so-called lambda cosmologies, that is, models of the universe in which the force of gravity and the force of cosmic repulsion played a key role. The force of repulsion proportional to distance was the consequence of the additional term introduced by Einstein in the equations of general relativity. The constant of proportionality is denoted by the Greek letter *lambda*. It is also called the *cosmological constant.*

Einstein had introduced the lambda term in 1917, two years after he had proposed the final set of equations of his new general theory of relativity. He had been motivated in this by his attempt to construct a model of the universe that was not only homogeneous and isotropic but also static. When in the early thirties the expanding universe idea took root, he realized that such models could be obtained from his unmodified equations of 1915 *without* the lambda term. Indeed, the work of Friedmann, Lemaître and Robertson had demonstrated this fact. So Einstein made a 180-degree turn and washed his hands off the lambda term calling it the biggest blunder of his life.

Eddington and Lemaître nevertheless persisted with the out of favour lambda because they could see in it some use in explaining the more complex features of the universe. In particular, they sought models of a particular type that might favour the formation of galaxies. To appreciate this work, let us first understand this problem.

The problem of galaxy formation

The models that the cosmologists used were over-simplified in the sense that the universe was taken to have a homogeneous distribution of matter. Even in the

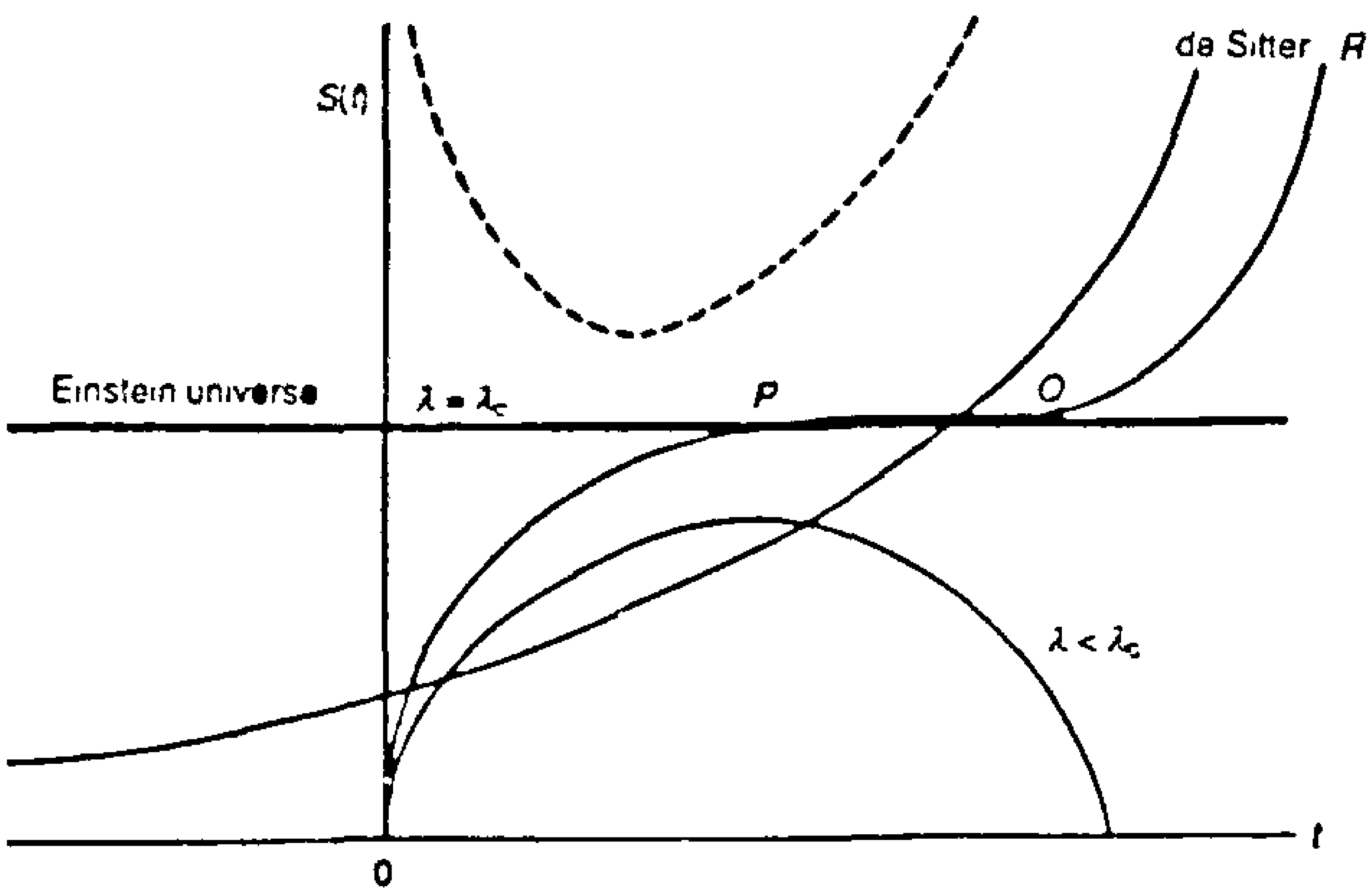

Figure 2. The variety of possible expanding models for a homogeneous and isotropic universe according to general relativity with the lambda term. The plot is of $S(t)$ the linear scale factor of space against the cosmic time t. For the critical value of lambda shown in the figure we get the static Einstein model with $S(t)$ = constant. For an empty universe we have the de Sitter model that expands exponentially. The model favoured by Lemaître and Eddington has the quasi-static phase from P to Q whose duration can be made arbitrarily long by choosing lambda close enough to the critical value.

thirties it was apparent that matter on the large scale is not distributed smoothly but is found to be in lumps ... a typical lump being a galaxy of some hundred billion stars like the Sun. How did such lumps form out of a homogeneous distribution? The force of gravity certainly helps in condensing matter into lumps. If a local distribution of matter has somewhat higher density its stronger tendency of gravitational attraction pulls it inwards to a state of still higher density and so the distribution condenses into a lump.

This process works if there is a small density excess to begin with and also provided there are no strong counterforces in operation. In a star like the Sun the gravitational tendency to shrink is countered by the pressures of hot plasma and radiation within it. Had these pressures not existed the Sun would have shrunk to a point in less than half an hour! In the cosmological scenario the expansion of the universe impedes the tendency to contract. So the problem in a nutshell is: how do we form galaxies in a universe that is expanding?

The Lemaître–Eddington approach to this problem was to invoke a cosmological constant of such magnitude that it almost balances the force of gravity during a critical phase in the history of the universe with the result that the universe is almost static for a sufficiently long period: almost like the static universe model first proposed by Einstein. This is when the galaxy formation process could be favoured.

This model seemed to have many attractive features. First, as we saw above, a static phase would favour the growth of condensations that become galaxies. Second, calculations suggested that the Einstein phase was unstable and that pertubations due to galaxy formation might trigger off expansion of the universe which would be more like the expansion of the de Sitter universe. Thus presently we are supposed to be in the expanding stage while in the past the universe had a long near-static Einstein stage. Finally, by having a static stage of long enough duration one may be able to understand and accommodate the ages of galaxies as estimated from their astrophysical evolution.

Work in this field kept Lemaître and others like G. C. McVittie, W. H. McCrea, W. B. Bonnor in the UK and N. R. Sen, A. K. Raychaudhuri and others in India active. However, the work of R. O. Lifschitz showed that the growth of perturbations in an expanding universe would not be powerful enough to explain the formation of galaxies. Problem also arises of sustaining the Einstein static phase long enough if it is unstable to perturbations of geometry or density.

The primeval atom

A variation of the above model is one in which the universe starts with zero scale of length, expands but then slows down to a halt and then coasts along in this quasi-static phase for a long time and then re-expands. Thus in the initial expansion the cosmological constant does not play a role. The slowing down occurs because of gravity and positive curvature, but by this time the universe has grown large enough for the cosmological constant to assert itself. In the second phase we see a tussle between the attractive force of gravity and the repulsive force of the cosmological term. The latter eventually wins, aided by instabilities of galaxy formation, and the universe expands rapidly.

This version of the Eddington–Lemaître model combines the simplest closed Friedmann model (Phase I), the Einstein model (Phase II) and the de Sitter model (Phase III). However, instead of the unstable Einstein phase the model begins in an explosion and the theoretician is forced to say more about this concept of a 'beginning'.

Perhaps Georges Lemaître is best remembered at the popular level as the originator of the idea of the primeval atom. The concept precedes the current one of big bang, both relating to the initial moments of the universe. For, most dynamical solutions of relativistic equations lead to the concept of a space–time singularity when the density, pressure, etc. of the universe were infinite and the space–time geometry itself became mathematically undefinable. This epoch may be identified with the beginning of the universe.

Lemaître's idea of a beginning was the break up of a gigantic primeval nucleus made of neutrons that became unstable. His nucleus was no more than a few light years across and its disintegration would be accompanied by radioactivity and explosive break up. He first wrote about the concept in 1931 in *Nature* (May 9) and although he did work more on it, he did not go into quantitative details. He felt that new physical laws would be needed to talk about the primeval atom, its lifetime, its decay products, etc. Among the relics of the explosion he conjectured that cosmic rays may be produced. However, the astronomical as well as the physics community preferred the more mundane and astrophysical theories of cosmic ray origin. Lemaître himself continued to work on the idea by studying the properties of cosmic rays.

Modern perspective

At best Lemaître's concept of the primeval atom was an attempt to get around the problem of singularity and to speculate about the early epochs in terms of physical laws, issues that still continue to be relevant. In that sense he was on the same wavelength as those who today speculate about the very early universe in terms of quantum gravity, cosmic strings, GUTs and cold dark matter.

It is, however, a sad state of the teaching and research in cosmology today that in the media oriented world of the COBE satellite and the Hubble Space Telescope pioneers like Lemaître are almost unknown. Indeed, it would not be an exaggeration to say that for the generation of cosmologists born after World War II the subject of cosmology seems to have really begun in 1981 with anything preceding that date only of archival value. Members of this generation would do well to educate themselves on how the subject developed and matured from Einstein to Lemaître.

They would discover, for example, that the problem of space–time singularity did bother those early pioneers as it does the theoreticians of today. Georges Lemaître was trying out speculative physics for his primeval atom in the same spirit as the cosmologists and particle physicists do now in their attempts to put together a coherent picture of the first moments after the big bang. And, Eddington and Lemaître were as concerned about how galaxies are formed as are their successors who are grappling with the same problem today.