PROF. K. C. KAR MEMORIAL LECTURE OF THE YEAR 1998

From big bang to black holes: the beginning and the end of time*

Amal Kumnar Raychaudhuri
(Retd.) Department of Physics,
Presidency College, Calcutta.-700 073, India

[Abstract : Observations have revealed a systematic red shift of light from distant galaxies. Interpreted as a Doppler shift, it indicates a recession of galaxies from us. It is usual to hypothesize that this recession is not peculiar to our locale but is universal and that there is a uniformity in the entire universe. Models of the universe built up in this way lead to a collapsed state of the universe at a finite past. This is termed the Big Bang and classical physics breaks down at this stage. One presents this as a beginning of everything.

In a way, a reverse situation occurs in the case of massive stars at the end of thermonuclear energy generation. Gravitation is then counter-balanced by the degeneracy pressure of fermions. However, equilibrium can he obtained only up to a limiting mass—a fact originally discovered by -Chandrasekhar in case of electron degeneracy. At higher densities, the predominant pressure may be due to neutron degeneracy and the mass limit is then about three times the solar mass. For higher masses, an uncontrolled collapse occurs to the stage of a black bole when it can no longer send any signal outside. Still later, classical physics predicts a state of infinite density.

The big bang and the black hole apparently signal the beginning and the end of time. Right now one can only hope and speculate that quantum ideas will show a way out.]

Cosmology deals with the universe at large and the first definitive information in cosmology came from the observation of the spectrum of light from distant heavenly objects. In the twenties of this century observation revealed a systematic red shift. By systematic, I mean that the observed red shift, quantified by $\delta\lambda/\lambda$, was correlated with the distance of the source. It was worth mentioning that $\delta\lambda/\lambda$ was a constant over the entire spectrum for any particular source. Originally the observations were limited up to small values of $\delta\lambda/\lambda$; but for large value of $\delta\lambda/\lambda$ the concept of distance became difficult to define. What was directly observed is a relation between the red shift $\delta\lambda/\lambda$ and the apparent luminosity of the source.

Assuming that the red shift arose due to recession (i.e., a Doppler effect) and translating the apparent luminosities to distance by introducing somewhat questionable ideas one got a relation between the recessional velocity and distance of the object which was approximately linear viz.,

$$V = HD$$

where V is the velocity of recession, D is the distance and H is a constant named after Hubble.

Assume for a moment that the velocity V was constant in the past, then at a time $D/V = 1/H$ all these objects would have been concentrated at

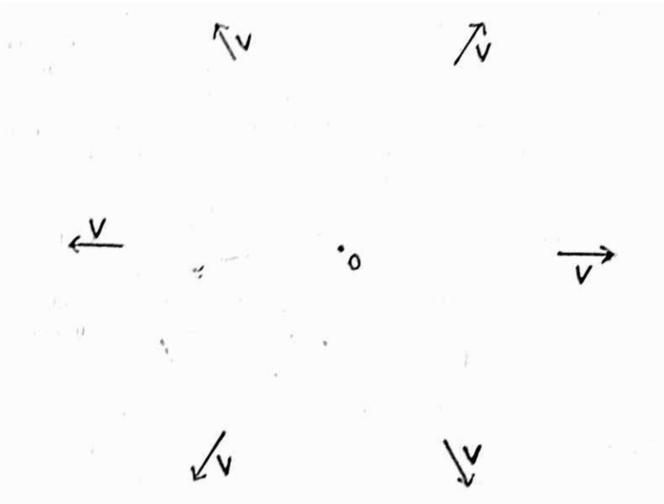

Fig. 1

O (Ref. Fig. 1) giving rise to an infinite density. One may like to introduce other variables like pressure, temperature, etc. into the picture (as was first seriously considered by Gamow) and the analysis makes all these variable also blow up.

Perhaps you may feel that the argument has been too simplistic–there might have been some forces which had so altered the velocities that instead of collapsing to a point, the system had rebound after a close approach. But the only effective force that comes to mind at first is universal gravitation and that would only reduce the value of the time to collapse to a point. But before giving an answer to this problem whether indeed the collapse can be prevented, let us specify two aspects of the problem we are faced with.

The first problem is the presence of infinities–infinite density, temperature, etc. Such a situation is referred to as the big bang. But there is another problem–one may ask what happened even before–i.e. history of the universe before the big bang. Unfortunately the theory cannot give an answer to this question–rather the thing is that our theory breaks down at this epoch and what was before seems a question devoid of any sense. Thus one says that time itself had a beginning at the big bang. This contradicts the common sense idea of time as an infinite flux without any beginning or end and also introduces a casual beginning of the universe–a supernatural element, if you like to say.

Which of these two difficulties is more serious? Opinions may well differ but later researchers have argued in favour of the beginning or end of time as the more serious one. Taking this viewpoint that the beginning (or end) of time even for a single realistic observe will be called a 'singularity'. Hawking and Penrose proved a famous theorem. The theorem runs like this. It sets out four conditions :

1. A unique ordering in time of events is possible i.e., there is no closed time like curve.
2. Gravitation is always attractive. Mathematically this means that the gravitating mass (i.e., the source of gravitation) is positive definite i.e.,

$$\left(T_{\mu_v} - \frac{1}{2} q_{\mu_v} T\right) v^{\mu} v^{V} \geq 0$$

which means in the simple case of a perfect fluid $(p + \rho) \geq 0$ and $(\rho + 3p) \geq 0$. This condition is violeted for the false vacuum which is imagined to be at the root of the inflationary scenario.

3. A so-called generality condition – which is a complicated mathematical condition.
4. There is at least one closed trapped surface where light is trapped.

The theorem then states that if the above conditions are satisfied then time will have a cut off either in the past or in the future. Of course the correctness of general theory of relativity is assumed.

Unfortunately few cared to study Hawking-Penrose theorem and popular science made the situation worse, so that the conditions underlying the theorem were overlooked and the distinction between the definition of singularity in Hawking- Penrose theorem and the big bang singularity was ignored and the belief gained ground that a big bang of infinities in density is inevitable. Indeed lately it has been shown that one can build singularity free cosmological models if the condition of trapped surfaces is violated.

Usual cosmological models in which there is a redshift lead to a time incompleteness in the past. An opposite situation occurs in case of the so-called black holes—an end of time so to say. To understand how this occurs we recall the work of Chandrasekhar. After thermonuclear reactions stop, pressure arises principally from electron degeneracy. As the density increases the Fermi energy. i.e., the highest energy states filled by the electrons becomes so high that the electrons become relativistic. Chandrasekhar showed that in this state of relativistic degeneracy, equilibrium between gravitation and degeneracy pressure can be obtaining only up to a limiting mass of the star. This limit. named after Chandrasekhar, is about 1.4 times the solar mass. More recently still higher densities have been considered when the electrons become so energetic that they may unite with protons producing neutrons and we have a star consisting primarily of neutrons. Pressure then arises primarily from neutron degeneracy and in nuclear and supernuclear densities other short range interactions come into play contributing to the pressure. But the conclusion of limiting mass persists; only the latest calculations push it up to about 3 times the solar mass. Now if the star's mass exceeds this limiting value, theory shows that there will be an unlimited collapse leading finally to a point of infinite density. What will happen after that? Again there is a breakdown of theory and we only say time stops there.

Physicists found it difficult to accept both the big bang at the beginning of the universe and the collapse to a point at the end of stellar evolution. Thus Chandrasekhar's work was criticized as leading to an absurd conclusion by Eddington and Landau doubted the applicability of quantum statistics in the extreme stage of the evolution of a star. On the other hand Einstein thought that the big bang conclusion was due to an application of general relativity which did not hold good for too high energy densities and intense gravitational fields. However these were negative arguments and within the realm of classical physics, no escape from the seemingly absurd conclusions in the two cases seem possible.

Perhaps the solution lies in a quantized theory of gravitation may be with a completely novel idea of time. All this is still in the realm cl hope and speculation. Just new we remain in the dark.