The Early Universe

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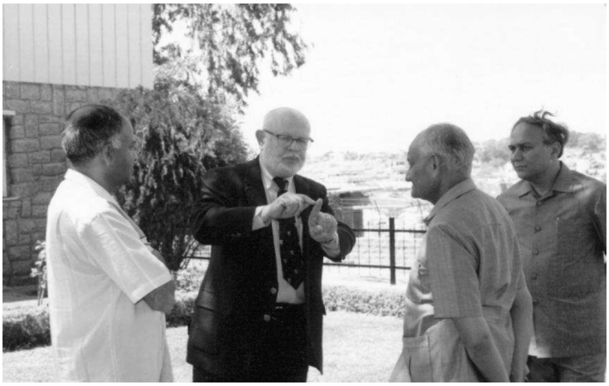

Fig. 1. William Fowler with Mr. G.P. Birla to his immediate left and Prof. J.V. Narlikar to his right

William Alfred Fowler was born in 1911 at Pittsburgh, Pennsylvania. He was raised in Lima, Ohio, from the age of two, as his parents shifted to this place. He had a great fascination for Steel Locomotives because of the Pennsylvania Railway Yard. In fact in 1973 he travelled on the Trans Siberian Railway from Khabarovsk to Moscow as a steam engine powered the train for nearly two thousand five hundred kilometers.

During his school days he was an accomplished football and baseball player. After school Fowler joined the Ohio State University, Columbus in Ohio to study ceramic engineering. However he soon became fascinated with Physics and transferred himself to the Engineering Physics department. Here he had to do all kinds of jobs for survival – as a waiter, as a dish washer, selling ham and cheese at the central market in Columbus and so on, earning five dollars for all his efforts. His undergraduate thesis was on “Focussing of Electron Beams”, experimental work carried out under Prof. Willard Bennett.

B.G. Sidharth (ed.), *A Century of Ideas,* 19–25.

On graduation Fowler joined the world famous California Institute of Technology as a graduate student for work under the famous C.C. Lauritsen in the Kellogg Radiation Laboratory. Fowler received his PhD in Physics in 1936 for work which showed the symmetry of nuclear forces between protons and neutrons. Thereafter he became an Assistant Professor at Caltech. However due to the second world war, the Kellogg Laboratory was engaged in defence research.

Lauritsen and Fowler reconverted Kellogg as a Nuclear Laboratory after the war and concentrated on nuclear reactions in stellar interiors. This was the starting point of nuclear astrophysics. Soon they confirmed that there was no stable nucleus at mass 8.

In 1951 E. Salpeter of Cornell came to Kellogg and showed that the fusion of three helium nuclei of mass 4 into the carbon nuclei of mass 12 could occur in red giant stars, but not in the big bang. Then in 1953 Fred Hoyle got an experiment to be performed in Kellogg which quantitatively confirmed the fusion process in red giants.

Hoyle had a great influence on Fowler. The original idea for stellar nucleosynthesis was first established by Hoyle in 1946 itself. Fowler spent a year in Cambridge, England in order to work with Hoyle, where they were joined by Geoffrey and Margaret Burbidge. The next year Hoyle and the Burbidges went to Kellogg and thus in 1957 they came out with a paper, “Synthesis of the Elements in Stars”. This important work demonstrated that all the elements from carbon to uranium could be produced inside the stars, starting with the hydrogen and the helium produced in the big bang. William Fowler was awarded the 1983 Nobel Prize for his researches, along with S. Chandrasekhar.

Through all these years Prof. Fowler retained a sense of liveliness, cheer and humour. He would recount an encounter with the late Indian Prime Minister Mrs. Indira Gandhi, who attended one of his lectures delivered in India. Later at lunch, Prof. Fowler recalled, with a guffaw, she told him, “Prof. Fowler you can worry all you want about the nuclear reactions inside the stars. I have to worry about how to feed six hundred million people.”

On another occasion he said, “I was travelling in a train when I got the news that I had won the Nobel Prize. I had presumed that Fred (Hoyle) had got it too. When I returned I discovered that he had been left out of the Nobel Prize. I immediately rang up Fred and told him that I would not accept the prize. Fred told me, don’t be a fool. Go ahead and accept it.”

Once I asked him, “Prof. Fowler have you ever thought about problems of society?” He immediately answered, “Yes”. Then he paused for a few more minutes and said, somewhat regretfully, “No, I haven’t. I have been far too involved in my work to think of anything else.”

Prof. Fowler had received any number of awards, honors and honorary degrees, apart from the Nobel Prize, including the Medal for Merit by President Harry Truman in 1948, the Barnard Medal for Meritorius Service to Science in 1965, the G. Unger Vetlesen Prize in 1973, the National Medal of Science presented by President G. Ford in 1974, the Eddington Medal of the Royal

Astronomical Society in 1978, the William A Fowler Award for excellence and distinguished accomplishments in Physics of the American Physical Society in 1986, the Legion d'Honneur Award from President Mitterrand of France in 1989, the Life Time Achievement in Science Award of the B.M. Birla Science Centre in 1990. He was elected Member of the National Academy of Sciences in 1956, Member of the National Science Board, Member of the Space Science Board. He also received honorary degrees from the University of Chicago, the Ohio State University, the University of Liege, the Observatory of Paris, the University of Massachusetts.

It is a great honor to have been invited to deliver the Fourth B.M. Birla Memorial Lecture following in the footsteps of Fred Hoyle, Philip Morrison and Abdus Salam. I must express my gratitude to Dr. B.G. Sidharth, Director of the Birla Science Centre, for all he has done to make the arrangements for the travel here and the stay here of my wife and myself so pleasant and so comfortable. Finally we are most grateful to Mr. and Mrs. G.P. Birla for their gracious hospitality at their home and its beautiful gardens here in Hyderabad.

B.M. Birla was a very great man – an industrialist with great interest and participation in science, engineering and education. He was very public spirited and founded a number of institutions for the education of young and old alike. I have tried to think of an American of comparable stature and attainments to B.M. Birla and have decided upon Thomas Jefferson. Jefferson wrote our Declaration of Independence and was our third President. He was the owner of a large agricultural estate in the state of Virginia and managed it with close attention to details. In those days the workers on such estates were considered to be slaves, but Jefferson was kind and generous to his slaves in contrast to many other landowners at the time. Jefferson founded the University of Virginia and interested himself in science and invention. I am proud to tell you that we Americans had a B.M. Birla and his name was Thomas Jefferson.

Now I will turn to my subject for today. In this talk I will take you back eleven billion years ago to the first few thousand seconds after the origin of our universe of which we and the earth and the sun and our galaxy, the Milky Way, are but a very small part. Many cosmologists think my age of eleven billion years is too short and many prefer a number more like fifteen billion. We need not worry about this detail today.

The title of my talk should have been OUR EARLY UNIVERSE not THE EARLY UNIVERSE. Many cosmologists, and I am one of them, believe that our universe is just an expanding bubble in an otherwise infinite universe both in space and time. This infinite universe consists of strange stuff about which we know very little except that it has exceedingly high density. From the basic equations which Einstein gave us we also know that this stuff exerts negative pressure. It is equivalent to Einstein's cosmological constant. In the Friedmann/Elinstein equation for pressure in the universe the cosmological constant term is preceded by a minus sign. Thus instead of compressing our expanding bubble it actually maintains the expansion. Eleven billion years ago a phase transition took place which changed this strange stuff into ordinary matter like you and me which has been expanding ever since. There may be other expanding bubbles but we will never be able to observe them through the dense intervening stuff.

Now why am I taking you back eleven billion years to the first few thousands of seconds? I am doing so because it was during this short interval that the major part of the first four elements in the periodic table, hydrogen, helium, lithium and beryllium, was produced as well as a small fraction of the heavier elements. Most of the heavier elements were produced in stars but that is another story. From the early production of the light elements we can learn indirectly a great deal about our observable universe. How that can be is my story today.

Before continuing let me make a disclaimer. When one has worked as long as I have on my subject today, one comes to be considered an expert. Well, I am no expert so let me tell this story. I think it is fair to say that we look up to members of the medical profession as experts. Well, more or less. But you know how it is. When you are ill, you go to your doctor. He diagnoses your problem, prescribes treatment and you do what he tells you. He is the expert. Well some time ago I sprained my left wrist. It was painful so I went to my doctor. He took X-rays and found it was not broken and was just a severe sprain. Then he dismissed me. But as I was leaving his office he said, “I want you to bathe your wrist in hot water three times a day.” I was flabbergasted. I said, “Doctor, my mother told me to bathe a sprain in cold water.” “Well,” he said, “your mother was wrong; my mother told me to use hot water.”

Now I will return to my subject.

George Gamow, the great cosmologist, argued that the universe erupted in a gigantic primeval fireball from an initial state of very high temperature and density. Fred Hoyle termed it the “Big Bang,” somewhat in derision, since he believed in a steady state model with no origin and no ending. Gamow’s ideas were based on Edwin Hubble’s discovery at Mt. Wilson that all the galaxies in our observable universe were receding from each other at enormous speeds. This was taken as strong evidence against a steady-state universe and in favor of a universe that was indeed expanding from a highly concentrated initial state.

Gamow’s expanding universe was uniform, isotropic and homogeneous. It is commonly referred to as the standard big bang model. I call it the obsolete big bang model for the reasons I’ll present later. In 1967 Wagoner, Fowler, and Hoyle calculated the abundances of hydrogen, helium, and lithium produced in the first thousand seconds or so at high density and high temperature. We, and later others, found agreement with observations on the abundances of hydrogen, helium, and lithium for the present mean density of ordinary matter like you and me in the universe equal to about 10% of the so-called critical density. The critical density can be calculated from Hubble’s measurements.

It can be understood as follows. If the actual density is more than the critical density then gravitational attraction between elements of matter will eventually stop the expansion and reverse it to a contraction which will finally lead to a "Big Crunch". If the actual density is equal to the critical density the expansion will continue forever but with a velocity of expansion which will eventually equal zero. In order for this to be the case it is necessary for Einstein's curvature parameter for the universe to be equal to zero. The surface of the earth is curved in two dimensions of space. Einstein introduced the idea that the universe could be curved in four dimensions, three for space and one for time.

Einstein's curvature parameter is indeed equal to zero in a variation of the Big Bang model proposed in 1981 by Alan Guth of the Massachusetts Institute of Technology. In this new model it was proposed that a very small fraction of a second after the Big Bang, the size of the universe, prompted by the energy release associated with a breaking of the unification between the fundamental forces of nature, underwent a period of tremendous growth, increasing its size by a trillion, trillion, trillion, trillion times. A trillion is a million million. In a short time the expansion rate of the universe decreased dramatically and Hubble's relatively show expansion was recovered. This spurt in the growth of the universe is known as Inflation and is referred to as the Inflationary Model.

The Inflationary Model requires that the average density of the universe be equal to the critical density. Thus, if Wagoner and Hoyle and I were right twenty-two years ago, 90% of the universe must consist of some form of exotic matter. Elementary particle theorists have proposed many exotic particles in recent years such as axions, photinos, and WIMPS. Don't ask me what they are but I will tell you that W, I, M, and P are the first letters of Weakly Interacting Massive Particles. None of these exotic particles have been observed at high energy accelerators around the world up to the present time and the search goes on. I think it will be fruitless.

Gamow's Big Bang was homogeneous, everywhere the same in the universe. Fortunately the Inflationary Model permits the early universe after inflation and during Big Bang nucleosynthesis to be inhomogeneous with regions of high density immersed in a low density sea as first pointed out by Edward Witten of Princeton. Then James Applegate of Columbia and his collaborators and Robert Malaney and I at Caltech showed that Big Bang nucleosynthesis in an inhomogeneous universe could reproduce the observations in hydrogen, helium, lithium and also beryllium with the mean density of ordinary matter like you and me in the universe equal to the critical density ($\Omega_b = 1$). There is no need for exotic particles. That is the message of my lecture today. The theorists can ignore the vision of axions, photinos, and WIMPS as well as the sugar plums which dance in their heads.

These conclusions are illustrated in Table 1 which shows that, for $f_v = 0.11, \Omega_b = 1$ and $A_0 \geq 0.3$, as defined in the table, the abundances of H_2, He_3, He_4, Li_7 and of course H_1 are approximately given by nucleosynthesis in an inhomogeneous universe. Moreover Table 2 shows that the primordial

Table 1. NUCLEOSYNTHESIS IN AN INHOMOGENEOUS UNIVERSE WITH $f_v = 0.11$ AND $\Omega_b = 1$, Malaney and Fowler, Ap. J. 333, 14 (1988)

	Average Mass Fraction			
	H_2	He_3	He_4	Li_7
$A_0 = 1$	1.6(−5)	3.0(−5)	0.25	4.8(−10)
$A_0 = 10^{-1}$	6.7(−6)	2.2(−5)	0.25	1.5(−9)
$A_0 = 10^{-2}$	5.0(−6)	1.1(−5)	0.25	1.5(−8)
$A_0 = 10^{-3}$	4.7(−6)	6.4(−6)	0.25	2.3(−8)
No Diffusion	4.7(−6)	5.6(−6)	0.25	2.4(−8)
Observed Limits	$>5(-6)$	$<3(-4)$	0.22 − 0.26	2 − 8(−9)Pop I 3 − 9(−10)Pop II
No Li_7 Problem for $A_0 \geq 0.3$				2 − 8(−10)*LMC*

Table 2. Be_9/H_1 IN OLD POP II STARS

STAR[1]	$log\, n(Be_9)/n(H_1)$
HD134430	< -11.9
HD74000	< -12.2
HD19445	< -12.3
HD140283 (Lowest observed value for Be_9/H_1 produced in the Big Bang)	< -13.2
SOLAR SYSTEM[2]	≈ -10.3
THEORY	
HOMOGENEOUS BIG BANG[3]	≈ -17.5
INHOMOGENEOUS BIG BANG[4]	≤ -13.0

abundance of Be_9 is also given by nucleosynthesis in an inhomogeneous universe [1–4]. The other parameters used in obtaining these conclusions are summarized in the final paragraph which follows.

A_0 measures back diffusion of neutrons into proton-rich region in which $Y_n^{(p)}$ would otherwise be small

$$Y_n^{(p)}(t) = A_0 Y_n^{(n)}(t)$$

$A_0 = 1$ for rapid diffusion relative to time scale for nucleosynthesis.
$A_0 = 0$ for no back diffusion.
$A_0 \geq 0.3$ yields mass fractions in agreement with observed limits.
Ω_b = baryon density/critical denslity
f_v = proton rich fraction of volume of the observable universe
$1 - f_v$ = neutron rich fraction of volume of the observable universe
$Y_n^{(p)}$ = mass fraction of neutrons in proton rich regions after back diffusion
$Y_n^{(n)}$ = mass fraction of neutrons in neutron rich region after back diffusion

Conclusion

And now my conclusion. What I have been telling you permits us to believe that we may well live in the simplest of all the universes compatible with Einstein's theories of special and general relativity. Its curvature parameter is zero, its cosmological constant is zero, its total energy is zero, its space-time is Euclidean, and its matter is stuff like us. I think Einstein would like that. I do, and I hope you do too.

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3. R.A. Malaney and W.A. Fowler (1989): $\Omega_b = 1/40$, Ap. J. 345, L5 (1989).
4. R.A. Malaney and W.A. Fowler (1989): $\Omega_b = 1$, $f_v R \geq 10$, $R \equiv$ ratio of density in proton rich region to density in neutron rich region.