THE PHYSICS-ASTRONOMY CONNECTION AT THE MOST FUNDAMENTAL LEVEL

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Physics and Astronomy are two disciplines which for a long time in the history of science appeared to move in entirely opposite directions, physics in the direction of the ultra small - molecules, atoms, elementary particles and astronomy in the direction of the big and the distant - the planets, the stars, the galaxies, and the universe itself. However in recent decades the two fields have come together in an unexpected way as beautifully depicted in fig. 1, known as the Glashow Snake. Notice that the tail of the snake is in its mouth, the body coiling round in a circle. This symbiosis and unification has tremendous implications for not only the two disciplines but also to science and philosophy in general.

Refering to Fig. 1, we see 'Man' depicted in the scale range of 150-200 cms. somewhere in the middle of the bottom half of the circle. As we move to the left we meet objects of smaller and smaller dimensions - the amoeba - the single celled most elementary form of life, the DNA molecule, the molecules of various elements, the atoms, the nuclei comprising of protons and neutrons and finally the species of elementary

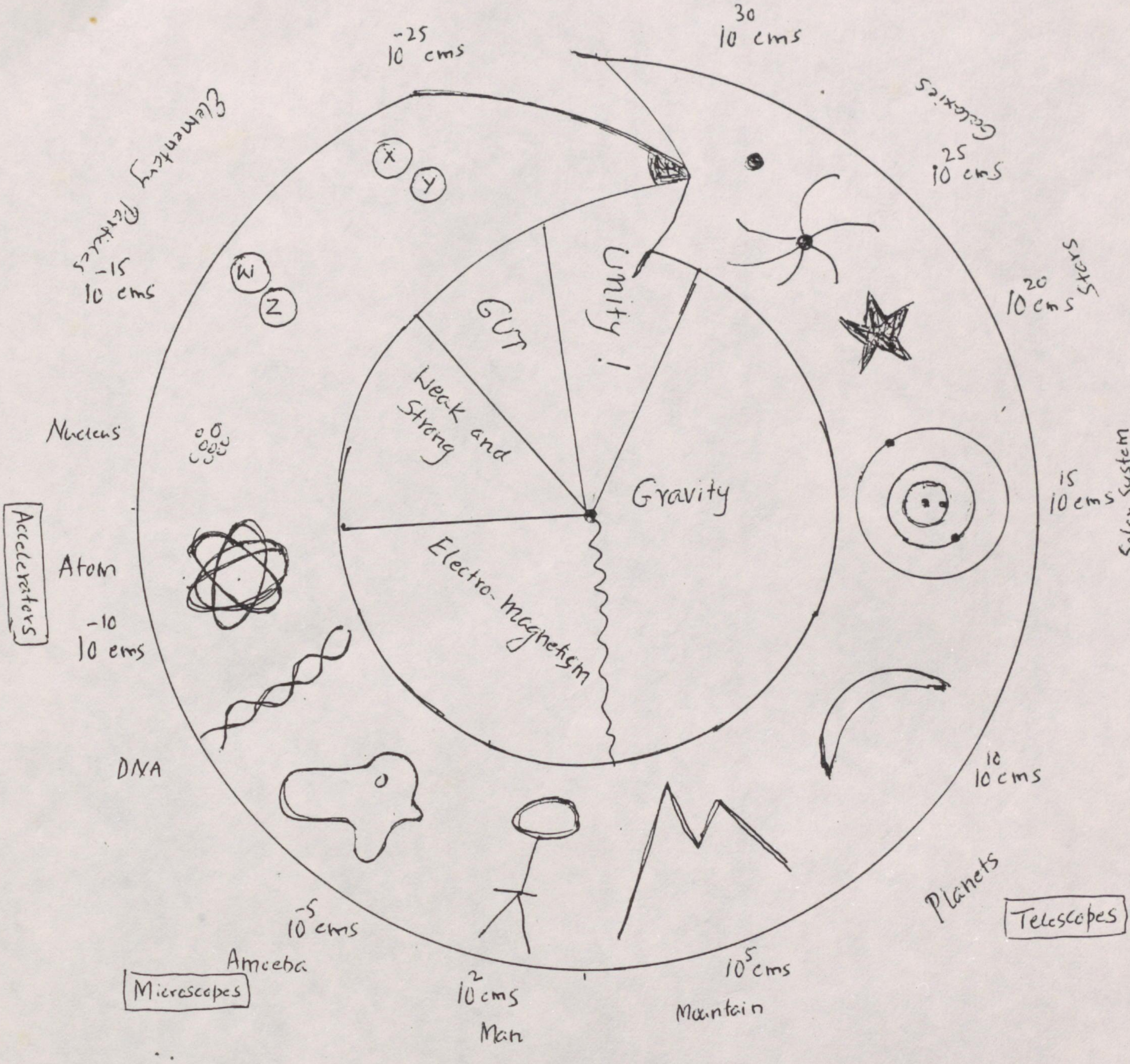

Fig. 1. GLASHOW'S SNAKE.

particles. The technological advances in the fields of high energy accelerators, and particle detection techniques and capacities for intricate analysis with computers have been chiefly responsible for opening up the vast vistas of the microcosmos, the first glimpses of which were given by cosmic rays - the particles that are accelerated somewhere in the depths of space, some of which on reaching the earth's atmosphere produce in collisions with air nuclei these elementary particles.

As we move to the right of Man in the figure, we encounter larger and larger objects and more and more distant ones discerned through telescopes of various size operating in different bands of the electromagnetic spectrum. Fig. 2 is a simple illustration of the types of objects that populate the universe - protons to stars to galaxies to the universe - ranging from 10^{-24}cms to 10^{30}cms and in mass scale from 10^{-24}gms to 10^{56}gms (estimated mass of the universe as a whole). The various properties of these constituents of the universe and the variety of physical phenomena proceeding in the environments of these objects have been revealed to us not only through optical astronomy, but in recent decades also from radio, infrared, ultra violet, X-ray, gamma and very high energy gamma ray astronomies. These new branches of astronomy became feasible with the technological developments in the fields of electronics and space technology.

One of the most significant findings of optical astronomical

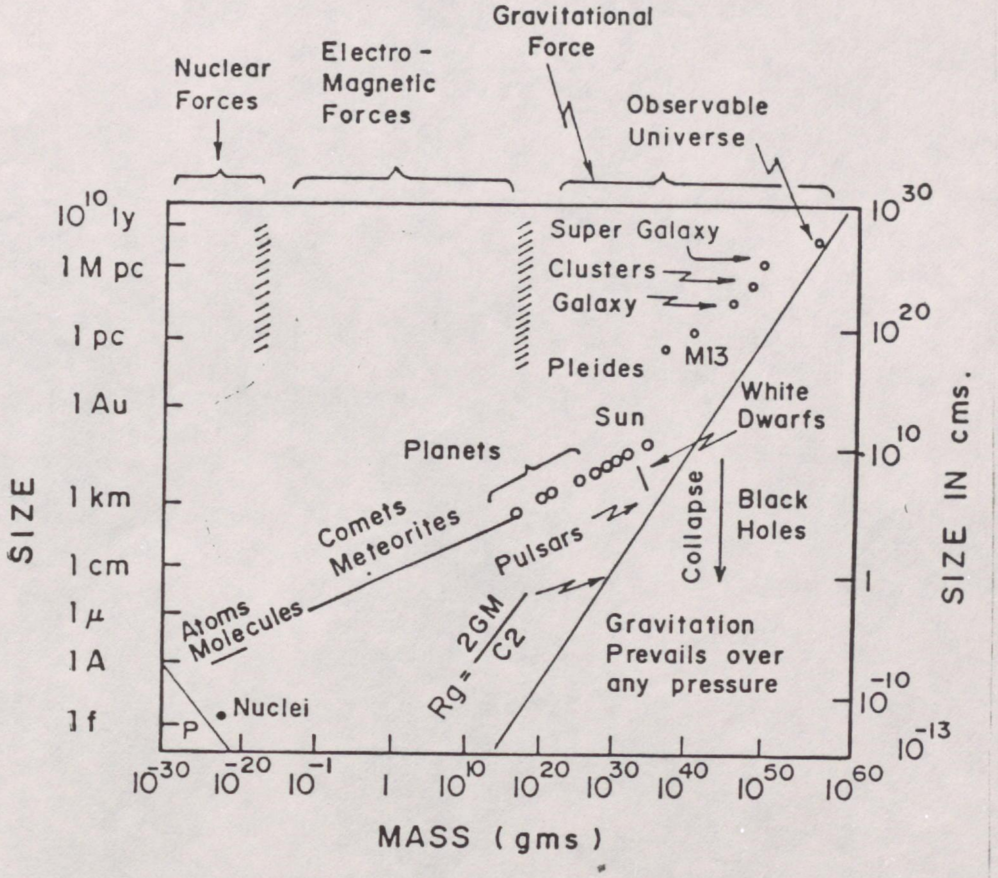

Fig. 2 Mass and size of the structural units of the universe
[From Kleczek THE UNIVERSE]

studies in the early decades of this century, was the discovery that the universe is not static, but is expanding - the galaxies are moving away from each other and suprisingly the greater the separation between the galaxies, the greater the velocity with which they are seperating. This realisation was the starting point of the fantastic idea that all the constituents of the universe might have been together in one place at a point of time in the distant past and the explosion of a "Cosmic Atom" of enormous mass was the cause of the universe as we see it to-day. This event has come be known as "the Big Bang". From the measured speeds of the receeding galaxies at different distances, it has been possible to estimate that this Big Bang explosion must have occurred about 20 billion years ago. The crucial supporting evidence for the Big Bang creation came in 1965 through a chance discovery by Penzias and Wilson while testing the performance of a horn shaped antenna that had been designed for signal receiption from communication satellites. In their tests they found an unaccountability excessive radio noise in the microwave region that corressponded to a balck body emission at a temperature of 3°K. The extreme isotropy and the spectral characteristics of this "microwave radiation" could be accounted for as the relic radiation that has expanded and cooled down to this temperature from the initial hot Big Bang. These discoveries and the subsequent investigations in great detail have enabled the formulation of the history of the universe as a function of time the chief characteristics of which have been given in the table 1. It may be seen that the universe started off with a temperature higher than $10^{32\circ}$K !

TABLE I

Important Milestones in the History of the Universe

Cosmic Time	Epoch notation	Red Shift	Nature of the Phenomenan
O	Singularity	Infinity	Infinite density; Zero of time
10^{-43} Sc	Planck Time	10^{32}	Particle creation begins
10^{-6}Sc	Hadron Era	10^{13}	$P\bar{P}$ annihilation
10 Sc	Lepton Era	10^{10}	$\overset{+}{e}\,\overset{-}{e}$ annihilation
2 mins.	Radiation Era	10^{9}	Nucleosynthesis of Helium, Deuterium
70,000 yrs	Matter Era	10^{4}	Matter dominates the universe
300,000 yrs	Decoupling	10^{3}	Universe becomes transparent to radiation
1.2×10^{9}yrs		10 - 30	Galaxies form
3×10^{9} yrs		5	Clustering of galaxies begins
4×10^{9} yrs			Formation of Milkyway Galaxy
4.1×10^{9}yrs			First Stars form
5×10^{9} yrs		3	Quasars born - Pop II Stars
10×10^{9} yrs		1	Pop I Stars form
15.2×10^{9}yrs			Parent Interstellar Clouds that gave rise to Solar System form
15.3×10^{9}			Collapsed Proto-Solar Nebula
15.4×10^{9}			Planets form
20×10^{9}			Homo Sapians appear (Just 10^{5} years ago)

What is mind boggling is that it has been possible not only to go back to the first few minutes of the Big Bang, but even to as small an interval of time as 10^{-43} seconds. The delineation of the happenings in the very early part of the universe is tied up with the developments that have taken place in the field of high energy physics.

Referring back to the Glashow Snake (fig.1) we see that basically four forces operate in nature - the gravitational force which is the most important force in the context of large bodies and large distances; the electromagnetic force reigns supreme as far as phenomena associated with molecules and atoms are concerned. As we go to the nuclear and elementary particle domain, two more forces - the weak force responsible for the spontaneous disintegration of particles (radioactive decay) and the strong force that holds the particles together inside the nucleus and also operates in the production of new particles in high energy collissions become the dominant ones.

Theoretical insights and experimental results with accelerators of higher and higher energy in the last three decades have led to some profound conclusions on these forces. In the ultimate analysis it turns out that the different forces are perhaps manifestations of one and the same force, the widely different features being connected with distance scales and energy transfers in the different phenomena observed. The scales of energy and distance of approach required for a full understanding of the behaviour of these forces are available only when we deal with high energy elementary particles and their interactions.

The electron and the proton were discovered as fundamental particles of nature in the very early part of this century through the study of discharge phenomena in low pressure gas tubes. The neutron another fundamental constituent of all matter was discovered in 1932 through the bombardment of α- particles from a radioactive source on beryllium. Between 1930 and 1953, a series of new particles that lived only for a very short time were discovered in the analysis of cosmic radiation passing through the atmosphere. Among the particles discovered in cosmic radiation are the positron (the anti-particle of electron), the mu-meson, the pi-meson, the k-meson, hyperons, and the $\Sigma^{\pm}$ and the cascade minus. These discoveries and the developments in the field of nuclear physics motivated the construction of higher and higher energy accelerators that became feasible with the advances in vacuum and electronic technologies. With the accelerator produced beams of protons and other particles not only it became possible to produce and study in detail the various elementary particles discovered in cosmic radiation but also to recognize the existence of extremely short lived particles, ($\sim 10^{-23}$ Sc) known as 'resonances'. Very elegant phenomenological theories followed which resulted in the prediction of some more new particles with special properties which were also discovered at the accelerators. However a disturbing feature was that the number of elementary particles swelled into hundreds. It looked as if all the simplicity and elegance of nature at the fundamental level was lost. To restore this simplicity and elegance "the quark model" of hadrons was proposed which proved eminently successful. In this picture all the baryons and mesons are composites of more elementary entities called 'quarks' and their anti-particles the 'antiquarks'. There are six flavours of quarks (see table II) and in each flavour there are three varieties distinguished by their 'colour'. The quark-quark forces are mediated by a set of new particles called 'gluons' which are massless bosons. Each gluon also carries the colour charge. In parallel to Quantum Electrodynamics the theory of quark-quark forces called Quantum Chromo Dynamics has been developed.

Though a free quark has not been seen either in cosmic rays or at acclerators, experiments on the scattering of electrons and neutrinos on protons have given full support to the quark structure of nucleons. An important property of the QCD force is that it depends on the momentum carried by the mediating particle, the gluon - surprisingly the higher the momentum, the weaker the force. As a result the quark behaves as a free particle at extremely short distances and is permanently confined within the particle since the force increases at larger distances.

While hadrons could be treated as composites of quarks, the leptons did not lend themselves for further division and had to be given

QUARKS - PROPERTIES

TABLE II

Generation	Nomenclature (Flavour)	Electric Charge	Baryon Number	Spin	Strangeness Number	Charm Number	Mass (Gev)
I	up (u)	$-1/3^{e}$	1/3	1/2	0	0	0.336
	down (d)	$2/3^{e}$	1/3	1/2	0	0	0.338
II	Strange (s)	$-1/3^{e}$	1/3	1/2	1	0	0.54
	Charm (c)	$2/3^{e}$	1/3	1/2	0	1	1.5
III	Top (t)	$2/3^{e}$	1/3	1/2	0	0	Not seen yet
	Bottom (b)	$-1/3^{e}$	1/3	1/2	0	0	0.5

- All the quarks have corresponding anti-quarks with opposite Electric Charge, Baryon Number, Strangeness and Charm Numbers.

- Each Flavour of quark has 3 coloured charge states (red, green and blue)

  For example $\Delta^- = d_r \cdot d_g \cdot d_b$

- Baryons are combinations of three quarks of different colour; meons are combinations of quark and anti-quark.

Quark Structure of Baryons (Examples)

p	n	Λ^0	Σ^+	Σ^-	Ξ^0	Ξ^-	Ω^-	Δ^-
uud	udd	uds	uus	dds	uss	dss	sss	ddd

Quark Structure of Mesons (Examples)

π^-	K^+	Υ	D	F
$d\bar{u}$	$u\bar{s}$	$b\bar{b}$	$c\bar{u}$	$c\bar{s}$

the same status as quarks. Fortunately the number of leptons, the light mass weakly interacting particles has not increased. In addition to the electron, the muon and the neutrino and their anti-particles, only the τ-meson was discovered as a member of this family and for theoretical reasons a τ-neutrino had to be postulated, though not established experimentally yet.

So at the fundamental level, we have moved from protons, neutrons, and electrons as constituents of all matters to quarks and leptons.

Among the four forces, the first unification clearly perceived theoretically and established experimentally is the electro-weak unification according to which the difference between the electromagnetic force and the weak force disappears at an energy scale of $\sim$ 100 Gev corressponding to a distance scale of 10^{-13} cms. The behaviour of the strength of the strong force with energy transfer and that of the electro-weak force is shown in the Figure 3. It is seen that there is a clear trend for the merger of the three forces at energy scale beyond 10^{15}Gev. This is too high an energy to be realised at accelerators even in the next century or in the subsequent ones. One of the crucial predictions of this Grand Unification (GUT) is the decay of the Proton with a life time of the order of 10^{30} years. Several experiments including the one at KGF have been carried out on Proton decay. While decay with a life time of 10^{30} years, and into the most dominent modes predicted by the socalled

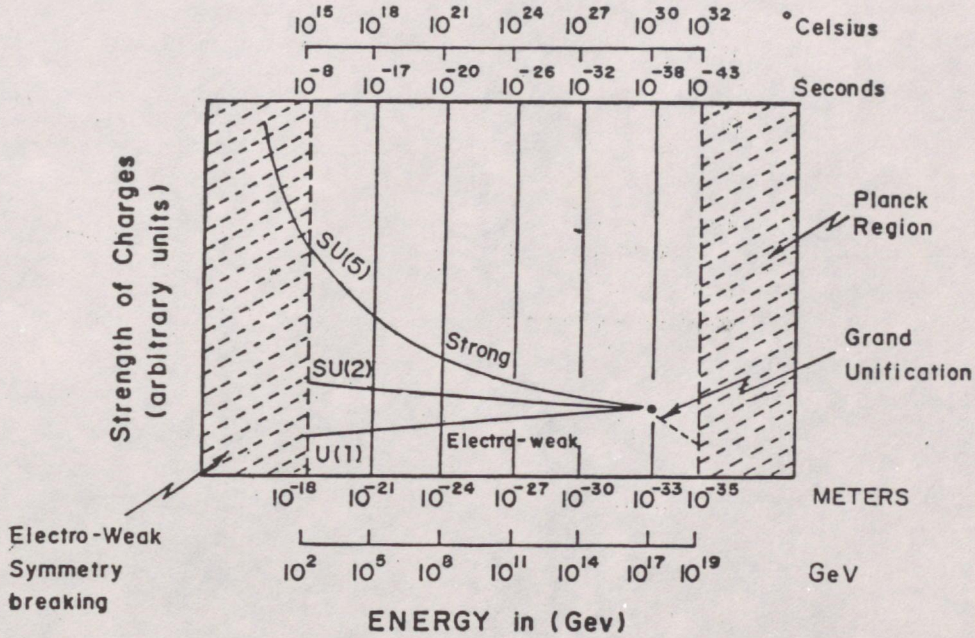

Fig. 3. The very early Universe and Grand Unification
[From M. Green SUPERSTRINGS]

standard theory have been ruled out, the possibility that the life time is longer than 10^{32} years and the decay modes distinctly different from the standard theory prediction are not so far ruled out. Yet another prediction of the GUT is the existence of massive magnetic monopoles. It is in this context that the particle physicists have become very much interested in the very early universe which turns out to be the highest energy accelerator that could ever be produced; and that was in existence 20 billion years ago.

The scenario of the early universe that has been formulated on the basis of many inputs from astronomy and elementary particle physics is as follows: (Table III)

As we go back in time, the universe was smaller and smaller and hotter and hotter. When the universe was 3 minutes old the temperature, (which is to-day 3°K,) was close to a billion degrees ($10^{9°}$K) and as we go to still earlier times for example around a microsecond the temperature should have been $10^{13°}$K. This would corresspond to the individual particles having an energy of a billion electron volts. At still smaller time say 10^{-12} second of Big Bang, the estimated temperature is $10^{16°}$K and the corressponding energy of particles 10^{12}ev, (Tev) Around 10^{-36} seconds the energy would be 10^{24}ev. The present extrapolation goes upto 10^{-43} seconds, when the temperature is $10^{32°}$K and the energy of the particles 10^{28}ev. It is seen therefore that in the very very early time of the universe 10^{-43} seconds to 10^{-36} seconds, the energy of the particles (essentially quarks) could have been sufficiently high to bring

TABLE III

Happenings in the Universe in the first Microsecond

Time From Big Bang	Temperature	Features of the Universe
10^{-6} Sc.	$> 10^{13}$ °K ($>10^{9}$ ev)	Non-gravitational properties change. Weak and Electromagnetic Interactions have the same strength.
10^{-13} Sc.	$> 10^{16}$ °K ($>10^{12}$ ev)	Spontaneous Symmetry breaking Higgs Mechanism operates to generate masses of $W^{\pm}$, Z^{0}
10^{-36} Sc.	$> 10^{28}$ °K ($>10^{24}$ ev)	Unification of strong and Electro-Weak forces. Production of massive lepto-quarks $X, \bar{X}$, massive magnetic monopoles, exotics.
10^{-43} Sc.	$>10^{32}$ °K ($> 10^{28}$ ev)	Quantum gravity becomes important. No good theories yet to make predictions.

about the unification of the three forces - strong, weak and electromagnetic. The feasibility of such an extrapolation is connected with the fact that the quark is a point particle (10^{-18}cms). The limit of 10^{-43} Sc is because of the lack of a clear quantum gravity theory. The evidence for this hot super dense state would be the production of exotic particles including the "magnetic monopoles" of very heavy mass (10^{15}Gev/c^2). Some of these could have survived upto the present time. Search for exotic particles and magnetic monopoles is on in many laboratories in the world.

This high temperature high density scenario of the early universe has proved to be of great value in explaining some intriguing aspects of the universe like the dominance of radiation over matter and the dominance of matter over anti-matter which have defied an explanation so far. Thus physics and astronomy have become disciplines which are inextricately intertwined at the most fundamental levels.

For those interested in knowing more about this exciting development, I would like to refer to an article of mine "The First Moments of the Universe" in Transactions of the Bose Research Institute Vol.50 No.1 1987 and the references therein.

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