STUDIES OF ACTIVE NUCLEI IN EARLY TYPE GALAXIES

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In an extensive program of spectroscopic, morphological, IR and radio studies of early type galaxies we have observed a large number of SO-galaxies in order to study the physical nature of the nuclear regions. Large scale photographs have been obtained with the 3.6 m and 1.54 m telescopes at ESO-La Silla as well as spectroscopic information, mainly with the 3.6 m telescope and image tube and the Image Dissector Scanner.

We have observed nuclei with the spectral properties of Seyfert I, II and III characteristics with low resolution spectra (171 A/mm). First provisional results have already been published by G.F.O. Schnur, W.A. Sherwood, 1980 (Patrick A. Wayman (ed). Highlights of Astronomy, Vol. 5, 193) at the Montreal IAU meeting.

More recent spectroscopic observations with the 3.6 m telescope have allowed us to study in more detail some of the galaxies with nuclear emission. These spectra were taken with a spectral resolution of 144 A/mm, allowing a separation of the blended lines H2, (NII)6548, 6584 and (SII)6717, 6731 and a reasonable determination of the FWHM of these lines and others.

M.P. Veron (1980, ESO Preprint 136) has studied the line widths of nuclear emission regions in galaxies and compared them with HII-regions.
Applying her results:

a). FWHM of HII-regions = 150 km/sec

b). FWHM of Seyfert I, II, III-galaxies > 200 km/sec

c). Position of HII regions and nuclear emission regions in galaxies in the log (OIII)/$H\beta$ - log (NII)/$H\alpha$ diagram

to our observations, we find that the vast majority of our galaxies do not have nuclei with characteristics of HII-regions, that the observed emission lines to be explained by photoionization from a continuum extending far into the ultraviolet (D. E. Osterbrock, J.S. Miller, 1975, ApJ., *197*, 535) or by shock-ionization (R.A.E. Fosbury, et al, 1978, M.N.R.A.S., *183*, 549).

We are also going to discuss NGC 4388 and NGC 4438, two faint X-ray galaxies. Their X-ray and H_β - luminosities extend the log H_β - log L_x - relation by about 2 orders of magnitude to the faint end of the QSO-Seyfert I relation (J.E. Grindlay, et al. 1980, ApJ., 239, L 43).

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SOME ASPECTS OF MODERN COSMOLOGY

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1. INTRODUCTION

When I was asked to review 'Cosmology' at this meeting I found myself in the position of a theoretician who has been asked to solve an extremely general problem. In such situations his own limitations as well as the limitations of the techniques available to him force the theoretician to simplify the problem by imposing symmetry arguments and to look for special solutions. As a theoretical cosmologist I am very familiar with this situation and have adopted a similar approach in my review talk. Realizing the impossibility of reviewing even the highlights of the entire field of cosmology in a span of $\sim 3 \times 10^3$s, I have introduced the simplifying qualification of 'some aspects' into the title of my talk.

Such a qualification inevitably exposes me to the accusations of 'personal bias', 'selection effects' etc., accusations which I do not deny. To those of you who detect a regional bias in what I discuss, I plead the fact that this is a regional meeting.

I have found it convenient to divide my review of cosmology into four areas:

1) Geometrical cosmology
2) Physical cosmology
3) Non-standard cosmology
4) Observational cosmology

Work in modern cosmology appears to be divided in these four areas, which are happily not mutually exclusive. That there is overlap between these areas will become apparent in some of the examples in this talk. I think elucidation might be needed for the third item in the above list. This item refers to *all* cosmological models which are different from the Friedmann cosmology with the hot big bang, popularly known as 'standard cosmology'. (Perhaps, judging by the religious fervour with which some workers in the field propagate standard cosmology, the adjective 'canonical' might have been more apt!)

2. GEOMETRICAL COSMOLOGY

The greatest input into modern theoretical cosmology came from Einstein's general theory of relativity. According to relativity the large-scale structure of the universe is describable by a Riemannian space-time manifold. Although the use of non-Euclidean geometry in cosmology began as early as 1917 with Einstein's paper on the static closed universe, the real spurt of activity in geometrical cosmology came in the 1960s. Many of the important investigations like the study of Einstein spaces [1], the classification of anisotropic models [2] and the nature of space-time singularities [3] have by now become textbook material. All these developments have been in the domain of classical physics, however.

There has not been a correspondingly dramatic breakthrough in quantum cosmology. This is because, geometrization of gravity and the non-linearity of the theory of relativity have made the problem of finding a satisfactory theory of quantum gravity extremely difficult. Experience gained from the highly successful quantum electrodynamics and the handling of field theories in general is not sufficient as a guide towards the solution, since these theories are in flat Minkowski space-time. Although many different approaches to quantum gravity exist, they do not necessarily lead to the same conclusion.

a) *Quantum fluctuations near the big bang singularity*

Take for example the question of cosmological singularity. The classical solutions [3] show that a space-time singularity is unavoidable. What does quantum gravity say? The electrodynamic analogy of the hydrogen atom tells us that the quantization of electron's motion around the proton leads to nonsingular stationary states while the classical theory had the electron spiraling inwards and falling into the proton. Does quantization of gravity similarly avert the space-time singularity? Experts in quantum gravity are not unanimous in their answer to this question [4].

In this context I wish to describe some recent work which may be of interest. Let us begin with the line element for a Friedmann-Robertson-Walker (FRW) space-time:

$$ds^2 = c^2 dt^2 - S^2(t)\left[\frac{dr^2}{1-kr^2} + r^2(d\theta^2 + \sin^2\theta \ \ d\phi^2)\right]. \tag{1}$$

where k (= 0, 1 or - 1) is the curvature parameter and S (t) the expansion factor. Both S (t) and k are supposed to be fully determined by Einstein's equations provided some observational input (Usually in the form of H_0 and q_0) is made. Consider now a conformal transform of this solution given by

$$ds^* = \Omega(t)\, ds, \tag{2}$$

where $\Omega(t)$ is the conformal function. The geometry given by ds* is *not* a solution of the classical Einstein equations, except in the trivial case of Ω = constant.

However, does quantum gravity permit non-trivial solutions of the kind (2)? The problem can be solved by using the path integral approach of Feynman in which Ω is a quantum variable. Instead of a unique classical solution given by (1) and describable by $\Omega = 1$, we now have a whole range of non classical ways of expansion. In analogy to the case of a moving particle we can say that the state of the universe is not described by the classical condition $\Omega = 1$ but by a whole range of Ω, each Ω having a probability amplitude associated with it. From this assertion we can go further and compute the mean value of Ω given by $<\Omega>$. It turns out that the mean is the classical one, i.e.,

$$<\Omega> = 1. \tag{3}$$

However, the fluctuations about the classical state *diverge* as we approach the classical big bang singularity:

$$\lim_{t \to 0} \ <(\Omega - 1)^2> = \infty \tag{4}$$

Thus while we may be able to assert that the mean of all the quantum mechanical alternatives is the classical singular solution we have to concede that the quantum fluctuations about the mean diverge. Hence the 'mean state' has no special significance [5].

Another investigation by Padmanabhan and the author [6] actually demonstrates that for a closed dust filled FRW model stationary states exist. This result is obtained by quantizing the classical variable S(t) in (1) for k = + 1. It can be shown that in the 'lowest' stationary state

$$<S^2>^{1/2} \gtrsim {\frac{Gh}{c^3}}^{1/2} = 1.5 \times 10^{-33} \text{ cm}. \tag{5}$$

thus we have natural interpretation for the Planck length of gravitational interaction as the *lower bound* for the size of a stationary quantum universe.

Padmanabhan [7] has also shown that the metric variables occurring in the anisotropic universes classified as Bianchi Type I - IX models can be quantized to yield stationary states. These investigations therefore suggest that at least in *some* cases quantization of gravity removes the classical space-time singularity.

A related problem is that of horizons. It has been a puzzle arising out of the isotropy of the microwave background that the early universe should have been so homogeneous in spite of very limited particle horizons. Except for the empty flat ($q_0 = 0$) model all classical FRW models have particle horizons. How and when did the different parts of the universe physically communicate and become well mixed to produce homogeneity? It was suggested in 1979 by Hoyle and the author [8] that quantum solutions may generate universes which have no particle horizons in the initial stages. This expectation is borne out by the explicit quantum cosmologies arising in the above mentioned path integral approach [5].

b) *The inflationary universe*

A different approach to the resolution of the horizon difficulty was recently proposed by Guth [9] through the concept of the 'inflationary universe'. Guth mentioned, apart from the horizon problem, another problem, 'the flatness problem' which was highlighted earlier by Dicke and Peebles [10]. This problem is as follows. The initial conditions in the early universe when its temperature was $KT \cong 10^{17}$ GeV (a value chosen to lie between the temperature for quantum cosmology and the temperature for phase transition in the Grand Unified Theories (GUTs)) would have to be very finely balanced if the universe were to end up with a present density parameter

$$\Omega_0 = \frac{8\pi G\rho_0}{3H_0^2} \tag{6}$$

in a relatively narrow range of 0.01 to 10. At the above initial epoch, the above density range corresponds to a fractional band of

$$\frac{\Delta\rho}{\rho} \sim 10^{-55} \tag{7}$$

How was such fine tuning possible?

Guth suggests that the difficulties will be resolved by *abandoning* the condition that the universe cools down adiabatically, thus conserving the entropy in a volume of radius proportional to S(t). Instead he suggests that the universe supercools to a temperature T_S much lower (by a factor ~ 10^{28}) than the critical temperature at which first order phase transition of the early matter should take place. The supercooling requires the nucleation rate of phase transition to be low. When the phase transition finally occurs enormous latent heat is released so that the entropy density is suddenly increased by a factor $(T_r \mid T_S)^3$ where T_r is the temperature of the reheated universe.

In the standard GUT scenario of the early universe, the scale factor satisfies the Einstein equation

$$\frac{\dot{S}^2 + kc^2}{S^2} = \frac{8\pi G}{3}\rho + \lambda \tag{8}$$

where ρ is the radiation density and λ is the cosmological constant. At a phase transition temperature of the order $kT_c = 10^{15}$ GeV the symmetry is spontaneously broken and an 'induced' cosmological constant appears out of the energy density of the false vacuum. This induced constant cancels λ and we are back with the standard (λ-less) Einstein equations.

In Guth's scenario the nucleation rate being small, the cancellation of the original λ term does not occur at $T = T_c$, but it occurs at a later stage. As a result the λ term in (8) begins to dominate the rate of expansion which now has the exponential (de Sitter) form. This leads to an 'inflationary' stage in which a small local bubble grows to enormous size until the above mentioned supercooling ends and the universe is reheated. Thereafter the universe follows the λ-less Einstein equations.

The horizon difficulty disappears because inflation has blown up an initial small local region to enormous dimensions. The blow up also reduces the curvature term in comparison with the radiation density term by a factor ~ 10^{56} thus compensating for the density contrast term (7) and solving the flatness problem.

However, Barrow and Turner [11] have pointed out that the inflationary phase cannot occur at all if the initial stage of the universe is highly anisotropic. In an anisotropic universe we can describe the state of expansion through a mean length scale factor S where S^3 is the volume scale factor. The anisotropic (shear) terms then modify the equation (8) to

$$\frac{\dot{S}^2 + kc^2}{S^2} = \frac{8\pi G}{3}\rho + \lambda + \frac{\Sigma^2}{S^6}\ , \tag{9}$$

where the last term is due to anisotropy. When the last term dominates, $S \propto t^{1/3}$ while in the isotropic phase which takes over at a large enough S, the universe reverts to the standard expansion factor $S \propto t^{1/2}$. It is then easy to see that in the early stage if anisotropy is large enough, the λ-term is never allowed to dominate the expansion and the universe will not inflate at all. I mention this result because it illustrates the crucial effect of space-time geometry in the very early stages of the universe.

3. PHISICAL COSMOLOGY

While discussing the inflationary universe I have already encroached upon the domain of physical cosmology. This branch of cosmology usually deals with three epochs. The earliest epoch is that of GUT, followed by the epoch of primordial nucleosynthesis which at a much later stage is followed by the epoch of galaxy formation.

a) *Lifetime of the proton*

One of the interesting issues for the GUT epoch is the current speculation of the lifetime of the proton, which is expected to lie in the general range of $10^{31\pm1}$ years. There have been many theoretical calculations [12 - 16] and Table 1 summarizes the broad spectrum of results on decay modes and branching ratios.

Table 1

Theory	Decay Mode	Branching Ratio
SU (5)	$p \to e^+ (\pi^\circ, \omega^\circ, \rho^\circ, \eta^\circ)$	70%
	$\to \bar{\nu}_e (\pi^+ \rho^+)$	20%
	$\to \bar{\nu}_\mu K^+$	5 - 10%
	$n \to e^+ (\pi^- \rho^-)$	80%
	$\to \bar{\nu}_e (\pi^\circ, \omega^\circ, \rho^\circ)$	17%
	$\to \bar{\nu}_\mu K^\circ$	2%
Pati & Salam ΔF = 0	$p \to 3\,\nu\pi^+$	80%
	$\to 3\,\nu\pi^+ \pi^+ \pi^-$	5-10%
	$n \to 3\,\nu$	40%
	$\to 3\,\nu\pi^\circ$	40%
	$\to 2\,\nu e^- \pi^+$	10-30%
	$\to 3\,\nu\pi^+ \ \pi^- \ \pi^\circ$	5-10%

Several groups all over the world are currently engaged in planning an experimental verification of this GUT-prediction. For an experimental search of nucleon decay the most favourable modes are those in which there are charged leptons in the final state. In theories involving fractionally charged quarks the dominant final states are those with e^+ and mesons (π, ρ, ω).

Claiming personal and regional bias I will briefly report on the Kolar Gold Field Experiment being conducted by the Tata Institute of Fundamental Research, Bombay, India in collaboration with the Osaka City University and Tokyo University of Japan [17]. In order to suppress the cosmic ray background the detector has been installed at a depth of 2300 m. It consists of a total of 1600 sealed proportional counter modules of lengths 4 m and 6 m and cross section 10 cm x 10 cm, filled with a mixture of 90% Argon and 10% Methane at a pressure equivalent to that of the underground site. From Monte-Carlo simulations it is estimated that for the most probable decay mode $p \to e^+ \pi^0$ each of the secondaries will traverse on the average 6 layers while for the other modes involving charged pions, muons etc at least 8 layers will respond. Hence the trigger for an event is generated primarily by 5-fold coincidences of pulses in consecutive layers.

The final detector configuration has about 140 tons of matter in the form of iron nuclei in the absorber and counters. For a background of < 1 event per year the sensitivity of the detector for lifetime measurements is

$$\tau = 9 \times 10^{29}\, \epsilon\, M_{\text{ton}} \times T_{\text{year}} \times (1\ \text{event/year})^{-1}, \tag{10}$$

where M = fiducial weight, T = duration of operation, ϵ = efficiency of event detection and identification. The estimate for τ is $\sim 3 \times 10^{31}$ yrs for dominant decay modes, at effective background of 0.1 event/year.

Each decay mode has a recognizable signature but great care is needed in detecting signals against the background. During the first half year of operation three events have emerged as possible candidates for nucleon decay. While this is encouraging, it is still too early to say that a decay has been observed [17].

From the point of view of the early universe calculations a positive result will be of great significance since GUT provides the big bang cosmologist the hope of understanding the origin of baryon asymmetry and the photon to baryon number ratio.

b) *Massive neutrinos*

Recent experimental indications that neutrinos might have a finite restmass have important implications for cosmology. As early as 1972-1973 Cowsik and McClelland [18, 19] had derived certain mass limits for neutrinos from the cosmological point of view. In recent years these calculation have been repeated with some refinements and modifications by several authors (see for example, [20], [21]). As pointed out by Cowsik and McClelland, two types of mass limits are possible from cosmology:

(i) The upperlimit on the total mass of all species of neutrinos assuming they are relics of the hot big bang arises from the fact that the density of the universe cannot be too high if its age is to exceed the oldest age estimates of matter in the universe. Recently Joshi and Chitre [22] have given general arguments to derive masslimits in globally hyperbolic space-times without the symmetries of standar cosmology.

(ii) The lower limit on the total mass of all species of neutrinos can be calculated from the virial discrepancy of the rich clusters of galaxies. If neutrinos make up the 'missing mass', we can ask the question as to whether the neutrino gas is more or less continuously distributed across the cluster or whether it is clumped round individual galaxies as halos. In the latter case the lower limit is pushed upwards.

Recently Cowsik [23] has given an argument to suggest that the latter possibility must hold. This argument is based on the calculation that the dynamical friction generated by the motion of galaxies through the neutrino gas would slow down the galaxies. The time-scale of slow-down of a galaxy of mass M is given by

$$T \cong \frac{V^2}{8\sqrt{\pi}\, G^2 M \rho_\nu F \ln \Lambda} \tag{11}$$

where $\ln \Lambda \approx 7$, V = mean velocity dispersion, F (~ 1) is a slowly varying function of V and ρ_ν = neutrino matter density in the cluster. (Note that T does not depend on neutrino mass) ρ_ν can be fixed on the assumption that the neutrino cloud makes up the virial mass discrepancy.

For the coma cluster the values $M \sim 10^{12}\, M_\odot$, $\rho_\nu \sim 1.25 \times 10^{-25}$ g cm^{-3} $R = 2 \times 10^{24}$ cm, $V \approx 10^8$ cm s^{-1} give $T \cong 10^{16}$ s. The slow-down time is thus considerably shorther than the cosmological time scale of $\sim 3 \times 10^{17}$ s. If we substitute for V higher values operating in the past we have to remember that they would imply an even larger virial discrepancy and hence a larger mass of neutrino gas and hence larger damping. In any case, if we fix T as the age of the cluster, we come up with a critical velocity V_c such that galaxies moving initially with $V < V_c$ would grind to a halt in time T. The cluster should therefore show a mixture of two populations of galaxies, one with essentially zero velocity and the other with a peak at $V \sim V_c$. No such dual population is seen in clusters.

From this calculation it follows that the dynamical friction of the neutrino gas must be reduced and this is possible if it sticks to the individual galaxies. Perhaps this may also account for the missing mass within the galaxies and, in particular, the flat rotation curves of the spirals.

If the galaxies are to retain neutrino halos the mass of the neutrino must be higher than in the first case where the neutrino gas is spread throughout the cluster. Cowsik estimates the upper and lower mass limits from these considerations to be

$$m_\nu \gtrsim 25\ \text{eV}: \qquad \sum_{\substack{\text{all}\\ \text{species}}} m_\nu c^2 < 50\text{eV} \tag{12}$$

in energy units and with the Hubble constant of

$$H_0 = 50\ \text{km s}^{-1}\ \text{Mpc}^{-1} \tag{13}$$

Thus it appears that we can just about accommodate two types of neutrinos of primordial origin. The limits in (12) become more stringent if a higher value of H_0 is used.

c) *Decay of neutrinos* — A related consideration of importance therefore is the possibility that primordial neutrinos might decay. For a detailed review of the various possibilities see Cowsik [24]. In particular, the question raised about the lifetime of the tau-neutrino (ν_τ) and its mass can be answered with the following inequality:

$$\frac{\tau_\nu}{m} > 10^{23}\ \mathrm{s}\ (\mathrm{eV})^{-1}, \tag{14}$$

for radiative decays at $m_\tau \approx 1\mathrm{eV}/c^2$. One consequence of this inequality is that the lifetime of a τ-neutrino with the restmass energy of a few electron volts is considerably longer than the age of the universe. Therefore if such neutrinos existed in the primordial era, they should survive to the present epoch and their masses should be included in the sum of equation (12). The inequality then becomes harder to satisfy.

To sum up, whether neutrinos are massive is a question relevant not only to particle physics, but it has profound implications for the canonical big bang model.

4. NON-STANDARD COSMOLOGY

Some of the issues discussed above would have been considered 'non-standard' a decade or two ago. For example, when Bondi, Gold and Hoyle suggested in 1948 that baryons may be created (in the form of hydrogen nuclei) continuously to keep the steady state universe going they were criticised as being too radical in suggesting the violation of the baryon number. Today some of the best brains in cosmology and particle physics are trying to give respectability to the picture wherein the baryon number is not conserved in a big bang universe. So what is considered 'non-standard' today may well become standard at a future date. I will describe some 'non-standard' concepts of today.

a) *G-variation* – is the gravitational constant G varying with time? The answer to this question is not given within the Newtonian framework which *could* accomodate the idea that G varies with the absolute time t. In general relativity the answer to the question is necessarily in the negative. However, a number of non-standard cosmologies [25 - 29] are based on the premise that gravity is a property of the large-scale structure of the universe and that in an expanding and evolving universe G should change with epoch. The general 'consensus' of such theories is that the rate of change of G at the present epoch is very small:

$$\left|\frac{\dot{G}}{G}\right|_{\substack{\text{present}\\ \text{epoch}}} \approx \beta h_0 \times 10^{-10}\ (\mathrm{yr})^{-1} \tag{15}$$

where β ($\lesssim 1$) is a model dependent quantity.

Although atomic clocks have improved considerably, the measurement of such a slow rate of variation is still beyond the scope of modern laboratory techniques. Astronomical and geophysical methods with all their attendant uncertainties have therefore been employed to investigate whether G does vary with time. In particular, the rate of change of the mean angular velocity n of the Moon round the Earth should be different if measured on atomic time and the ephemeris time, if G varies. By measuring this difference Van Flandern [28] has concluded that G does *decrease* at a rate suggested by [15]. Van Flandern claims that the probable errors in the various sources of data have narrowed down considerably and that a zero rate of change of G is probably ruled out. There are others, however, who still claim that the effects of the tidal force between the Earth-Moon system which also makes a contribution towards changing n are difficult (if not impossible) to separate out from the effects of G-variation. Thus at present we can neither rule out G-variation nor claim that the relativity theory has been disproved.

If G-varies, then in some non-standard cosmologies the non-Planckian nature of the microwave background (MBR) spectrum is explained. It was argued by Narlikar and Rana [29] that in a number of G-varying cosmologies the equilibrium distribution of radiaton at any epoch t has the spectrum

$$F(\nu) = \frac{G(t_*)}{G(t)}\,\frac{2\pi h\nu^3}{c^3}\quad \left(e^{h\nu/kT} - 1\right)^{-1} \tag{16}$$

where t_* is some fixed epoch. The spectral function therefore has two parameters t_* and T and it is possible to give a 'best fit' to the existing data [29] which lies within 1σ from (16) for $T \cong 2.53$ K and $G(t_*)/G(t_0) \simeq 1.77$. A satisfactory explanation for the non-Planckian spectrum is still to emerge within the framework of standard cosmology.

b) *Origin of MBR.* Is the hot big bang the only way of generating the MBR? In the context of the big bang the present background temperature of 3K is not derived from the early universe scenarios. Instead, it serves as an input for fixing the parameters such as the redshift at which the radiation was thermalized. The photon to baryon number ratio is also a number to be explained within the framework of the hot big bang.

Within the framework of astrophysics, however, the 3K value of the MBR temperature is highly suggestive. If we assume that all helium was produced in stars, thus implying increased stellar activity in the past, the energy density of starlight so generated would be comparable to that currently observed in MBR. This was pointed out as early as 1968 by Hoyle et al [30]. However no concrete process was forthcoming for thermalizing bulk of this starlight. In 1975 intergalactic graphite needles were suggested as possible thermalizers [31]. In 1978 Rees [32] proposed Population III stars at redshifts $z \sim 200$ as sources of starlight which was thermalized by dust etc. at subsequent epochs. In 1979 Silk et al [33] considered a detailed model in which the present MBR is made of a primordial component together with a small contribution from Population III stars. The aim of this work was to explain the MBR spectrum together with its observed non-Planckian deviations.

Recently Rana [34] has gone one step further by working out a model in which there was increased stellar activity at the *more recent* epochs of $z \sim 6 - 12$ the light from which was thermalized by graphite whiskers. Rana has shown that this model not only produces the observed MBR spectrum but it also ensures that adequate helium is produced in stars. (Indeed, observations of low helium, e.g. $Y \lesssim .15$, may prove embarrassing for the standard model but not for this model.) Enhanced stellar activity in the past implies that galaxies were brighter and this is consistent with the prevalent ideas on luminosity evolution. The model is constrained by requirements of large and small scale isotropy. The latter limits in particular can be tested observationally.

I have classified this work as non-standard since by making MBR of recent origin it pulls the rug from under the base of the standard model.

5. OBSERVATIONAL COSMOLOGY

From observational point of view I think two important issues need to be settled first.

a) *MBR* – Because it plays such a key role in the standard picture it is necessary to make further checks on the MBR. I can think of three such checks.

(i) Further observations from above the atmosphere to verify whether the departures from the Planckian form observed by Woody and Richards [35] do exist.

(ii) Improved limits on small scale anisotropy to place constraints on theories of galaxy formation.

(iii) Observations of MBR from places remote from the Earth with the help of instruments in spacecrafts leaving the Solar System.

The last named observation should be interesting if we recall that all direct observations of such an important concept have so far been made only from the Earth. (The only indications that MBR might exist elsewhere come from the CN molecule transitions in the atmospheres of certain stars in our Galaxy. The evidence for the Zeldovich-Sunyaev microwave dip in clusters of galaxies is still marginal.)

b) *Quasar redshifts* – Are quasar redshifts cosmological? Even though more than 1500 quasars are known, the answer to this question is still in some doubt. To me evidence of the apparent superluminal separation of radio source components in some quasars and the evidence on quasar galaxy associations of discrepant redshifts are difficult to explain on the cosmological hypothesis (CH).

The former type of evidence requires somewhat contrived scenarios [36, 37] while the latter demands highly accidental juxtapositions. In this connection I should mention Arp's [38] recent analysis of the probability of chance occurrence of quasars near galaxies which are companions to NGC galaxies in a specified region of the sky. Because Arp has been criticised previously on the grounds that he does not clearly specify his selection criteria, in this case he has been careful to lay down the ground rules at the outset. And with these selection criteria he computes the probability of chance juxtaposition of quasars next to the galaxies to be as low as $\lesssim 10^{-17}$. If the quasar density is made as high as 100 per square degree at 20^{m}, this probability is still no higher than 10^{-5}. If CH is correct why does Arp find such improbable configurations?

6. EVOLUTION ⇔ BIG BANG?

The quasar problem mentioned above is important because if quasars are really distant as CH implies, then they provide us with probes of the universe of much earlier epochs ($z \lesssim 3.5$) than galaxies do ($z \lesssim 1.0$). The various evolutionary implications drawn from the quasar data then become important. The conclusion based on quasar data that the universe is strongly evolving, cannot be drawn if CH is wrong.

Even if CH turns out to be correct and the universe is shown to be strongly evolving can we draw the conclusion that we live in a big bang universe?

There is a point of logic here that is often ignored. The point is simply that an evolving universe is consistent with the big bang but *does not imply* a big bang. The quasars take us back to epochs of $z \simeq 3.5$. The big bang epoch lies at $z = \infty$. Much may have happened in between.

The conclusion evolution ⇔ big bang represents a hang over from the early 1960s when the cosmological controversy centred around two types of models the standard models and the steady state model. Evolution was meant to demonstrate that the universe is not in a steady state and hence that it must have originated in a big bang. Models not belonging to either type also exist [39] and may have useful ideas to offer on the unsolved problem of galaxy formation [40].

It is nearly two decades since the height of the above controversy and we are now on the threshold of observational breakthroughs with the launching of the Space Telescope in ~ 1984. By committing themselves strongly to one type of models the cosmologists of today may be repeating the mistake of their predecessors at the turn of the century of believing that our Galaxy comprises the whole of the universe.

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DISCUSSION

V.M. Blanco : In discussing non-conventional cosmologies, in the specific case of a possible variation in the value of the gravitational constant, you mentioned van Flandern's work. Can you comment also about results obtained with laser lunar ranging?

Answer : Laser ranging observation (e.g. by Shapiro and his colleagues) have placed upper limits on $|\dot{G} / G|$. For example, $\beta > 1$ appears to be ruled out. However, most G-varying cosmologies make predictions of $|\beta| < 1$. So they are not yet ruled out.

K. Supelli : You spoke of quantum fluctuations in the past, that is if we go back to the Big-Bang. The fluctuations do not exist in the general theory of relativity. According to Penrose's theory of twistor this quantum fluctuations do exist, but not in the past nor in the future, but it exists *today*. I would like to ask your idea about this twistor theory of Penrose, do you think that this theory could answer the missing link between the general theory of relativity (classical cosmology) and the quantum cosmology?

Answer : I am not an expert in twistor theory which is one of the possible approaches to quantum gravity. There are physicists (like J.A. Wheeler, for example) who take the view that the concept of space-time continuum breaks down at the quantum level. Your remark about there being no fluctuations in general relativity applies to *classical* theory. When you quantize it (e.g. by the path integral approach described here) fluctuations must appear.

J. Silk : 1) Light element abundances, such as deuterium and Helium-3, Helium-4, and the universality of the He^4 abundance do extend the domain of ignorance in your part light curve diagram, to a redshift of a least 10^9.

2) If the cosmic microwave background radiation is entirely non-primordial and thermalized by graphite grains, then a high (near--solar) abundance of carbon must be required. How then can you account for population II abundances?

Answer : 1) We seem to have a good theory of primordial nucleosynthesis at temperatures $\gtrsim 10^{\circ}$ K although even with the primordial Helium abundance there are difficulties (of over production) if there are too many leptons around. We also have a fairly good theory of the universe up to the recombination era ($\zeta \sim 10^3$). However, we do not seem to have as good a theory for the redshift range $3.5 \lesssim \zeta \lesssim 10^3$. This is what I call domain of ignorance.

2) The abundance of graphite required is given by a smoothed out density in the range 10^{-35} - 10^{-34} g cm^{-3}. Rana has discussed this in detail and argued that there is no difficulty of getting this much carbon from stars.

Hanes : Do you consider the apparent superluminal expansion of quasars to be a real problem for cosmology. After all, such effects were first seen in a galactic nova (which sure poses no cosmological problem) and explained in terms of geometrical effects. Presumably we can allow ourselves the liberty of generating similar models to explain the apparent superluminal expansion of quasars without compromising their cosmological nature.

Answer : I know, scenarios exist for explaining the apparent superluminal separation in quasars without giving up CH. I myself was a coauthor of one such idea described in a paper on gravitational bending [Ref. *37*]. However, *all* scenarios proposed so far appear to be somewhat contrived if not impossible. Hence my skepticism.

THE LOCAL SUPERCLUSTER

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An attempt is made to illustrate the three-dimensional distribution of nearby galaxies. There is an evident overdensity of galaxies in the north galactic hemisphere that has been called the local supercluster. It is argued that this system is comprised of two distinct components: a disk component with 60% of the luminous, and a halo component with 40% of the luminous galaxies.

With regard to the halo component (i) almost all luminous galaxies are associated with only a small numbers of clouds, (ii) as a consequence, most of the volume off the disk of the local supercluster is empty, (iii) the clouds in the halo are sufficiently separated from the disk so that the two-component distinction seems warranted, and (iv) at least the more prominent clouds in the halo seem to be prolate structures with their long axes directed toward the Virgo cluster. This elongated structure may be attributed to tidal effects that were important at the epoch of the formation of the halo clouds. A tentative limit for the date of that epoch is $Z \lesssim 8$.

With regard to the disk component (i) the ratio of the longest to the shortest axis is 6 to 1 (practically independent of velocity effects), and (ii) the absolute rms dimension of the short axis is $\pm$ 1.1 h^{-1} Mpc ($h = H_0/100$ km s^{-1} Mpc^{-1}). For the disk component to be so thin either (i) we are viewing the disk at the moment of collapse, (ii) there is a great deal of unseen matter in the disk, or (iii) random motions normal to the disk are less than 100 km s^{-1}. If velocities normal to the plane of the local supercluster are very low, the implication would be that the disk was formed through dissipative processes.

The thinness of the disk of the supercluster, the extreme segregation of galaxies into a small fraction of the volume available, and the low local random motions are all evidence which weigh heavily against gravitational clustering models in which galaxies formed before superclusters and in favor of the viewpoint that galaxies fragmented out of larger scale structure.

DISCUSSION

David Hanes : 1) Can you say again how you deduced distances to single galaxies?
2) Then can you (i) explain how you handled the large negative velocities in the Virgo cluster, and (ii) explain how meaningful are your low random velocities in groups? After all, the groups are defined by their near coincidence in velocity, so one should perforce deduce low random velocities within such groups.

Answer : Strictly from velocities, assuming a smooth Hubble law.