GENERAL DISCUSSION AND SHORT CONTRIBUTIONS

(Chairman: M. J. Rees)

Ames: I wish to make two brief comments relevant to the theory of galaxy formation through primordial turbulence. These results are based on work which I am doing jointly with Bernard Jones.

First, I agree completely with Dr Nariai that the amplitude of the density inhomogeneities at a point is determined by the superposition of all acoustic waves generated within the acoustic cone by the turbulence. Our recent work shows however that when one takes into account the non-linear interactions between the turbulence and self-generated acoustic modes, the waves do not propagate appreciably but are dissolved over a distance of the order of two wavelengths. Hence the approximation used in the calculations of Silk and Ames (1972) in which the propagation of the acoustic waves is neglected is not unreasonable for obtaining the amplitude of density inhomogeneities. The high acoustic depth of the medium is due to scattering by the turbulence.

On the other hand, these non-linear turbulence-acoustic wave interactions steepen the $1/\mathbf{r}$ spectrum for the density inhomogeneities which Dr Silk and I found. Since the turbulence has a scale smaller than that of the acoustic waves by a factor of the Mach number, which at the epochs we are considering is much less than one, the interactions enhance the larger wave-number components at the expense of the low wave number components. Thus if the vortical theory for the formation of inhomogeneities is correct, it appears that large scale concentrations such as clusters and superclusters would be increasingly weaker with scale size, or form much later than the galaxies themselves.

Zel'dovich: There is an important distinction between the theory of primordial density perturbations and the vortex or whirl theory. In the adiabatic fluctuation picture, the evolution of the model follows very closely the Friedmann models. The perturbations which eventually form galaxies are so small that they do not influence the predictions of the Friedmann models in the synthesis of the light elements which was described by Dr Wagoner. Thus the predicted chemical abundances agree well with observation. In the whirl theory the vortex motions result in significant perturbations of the metric in the early stages. I do not know what the initial conditions are in the whirl theory and it is not clear what the resulting chemical composition will be. Perhaps it will be alright.

Novikov: I should like to stress that it is impossible to obtain the whirl theory from models in which there is a chaotic beginning to the expansion.

Rees: Does Dr Zel'dovich's point mean that there has to be a cut-off on small scales in the spectrum of the turbulence?

Ozernoy: The whirls may be produced during the early stages of the expansion. For example, Silk has shown that initial shear superimposed on some isotropic

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expansion may produce vortices. So far as the chemical abundances is concerned, one can obtain any answer one likes depending on the initial conditions. Therefore the chemical composition is inconclusive as a test to resolve the question of primordial inhomogeneities or primordial whirls.

Rees: It seems to me that a virtue of any theory of galaxy formation is to explain a lot with as few parameters as possible. It seems to me that Dr Ozernoi has only one free parameter – the amplitude of his turbulence – which can explain quite a lot. In Dr Zel'dovich's theory, there seem to be two parameters, the amplitude of the perturbations and a cut-off at large wavelengths.

Zel'dovich: My one parameter which is associated with metric perturbations of order of magnitude 10^{-4} gives galaxies, clusters of galaxies, the primordial chemical composition and the specific entropy of the Universe.

Rees: In your report today you used $\Omega = 0.1$. Would you have been able to use the same perturbation spectrum for the case $\Omega = 1$ without contradicting the observed lack of large scale temperature fluctuations in the relic radiation?

Zel'dovich: In this case it may be marginal.

Rees: Then Ω may be a second parameter.

Zel'dovich: Ω is *not* a free parameter. Nature gives us Ω. Ω is *not* the free parameter of a theoretician.

Ozernoy: I should like to emphasise that the final spectrum of turbulence is very weakly dependent on the initial whirl spectrum as I described in my talk. I should also like to draw attention to the fact that it is rather difficult to reconcile the theory of primaeval inhomogeneities with the present measurements of Parijskij of the small scale isotropy of the relic radiation. The calculations made by G. V. Chibisov for the 'pancake' model have taken into account the form of the initial spectrum of the density perturbations as well as the polar diagram of the radio telescope used and he gives an expected value for ΔT of

$$\Delta T = 4 \times 10^{-5}\, \Omega^{-5/4}\, \frac{1+z_f}{1+4} \exp(\tau/0.25)\ \mathrm{K}$$

The figures are normalised to a redshift of galaxy formation of $z_f = 4$. The value of ΔT contradicts the observations of Parijskij ($T_{\mathrm{obs}} < 8 \times 10^{-5}$ K) for all $\Omega < 0.6$ (Hubble constant $= 75$ km s^{-1} Mpc^{-1}). The contradiction disappears if the optical depth to Thompson scattering τ is sufficiently large. To do this, it is necessary to remove the redshift of galaxy formation to $z_f > 8$ to obtain $\tau > 1$. However, this will give a quite different model of galaxy formation.

Silk: It seems to me that there are at least two free parameters, the initial amplitude of the fluctuations and their initial time.

Zel'dovich: The metric perturbations are constant in the limit of zero time. Zero is **not** a parameter!

Puget: If instead of primordial turbulence you consider turbulence generated by annihilation pressure in the symmetric hot big-bang, you end up with no free parameters.

Galaxy Formation: Dissipation of Turbulence and Matter-Antimatter Annihilation

N. Dallaporta, L. Danese and F. Lucchin: We have reconsidered the problem of galaxy formation from primeval turbulence, taking into account the dissipation of turbulence (Dallaporta and Lucchin, 1973). The main physical assumptions are the Kolmogoroff law ($v \propto l^{1/3}$) in the subsonic regime ($z > z_{\mathrm{rec}}$), and the extended Kolmogoroff law ($v \propto l^n$, where $n > \frac{1}{3}$) in the supersonic regime (von Weizsäcker, 1951). The dissipation law for the subsonic regime has been derived from the well known Heisenberg equation of statistical turbulence (1948a, b), i.e. $v \propto t^{-2/3}$ in Kolmogoroff range. In the supersonic regime for continuity with the subsonic regime and similarity properties we assume a dissipation law $v \propto t^{-1(n+1)/2}$, where n is the parameter of the extended Kolmogoroff law; this is a rather rough approximation but, despite our neglect of energy losses due to shock waves, useful insight on the cosmological parameters connected with galaxy formation is obtained. Our main conclusions are:

(i) by making the extreme assumption that the maximum turbulent velocity at z_{eq} is $c/\sqrt{3}$, turbulence will survive until z_{rec} only for density parameters $\Omega \lesssim 0.3$, otherwise galaxies would not form;

(ii) in order to obtain a maximum mass of 10^{12} $M_\odot$ and an angular momentum per unit mass of about 10^{30} cm^2 s^{-1} Ω must be $0.15 \lesssim \Omega \lesssim 0.2$;

(iii) the separation time, practically simultaneous for all galaxies, is given by $z_{\mathrm{sep}} \sim \sim 700$. The values of z_{sep} and of Ω so obtained are respectively higher and lower than previous results without dissipation (Dallaporta and Lucchin, 1972); this is due to the energy supply compensating dissipation.

A possible energy input mechanism (Dallaporta, *et al.*, 1973) in the framework of Omnes theory (1971a, b, c) and on the lines of the work of Stecker and Puget (1972) would be matter-antimatter annihilation. In this way the maximum turbulent velocity is no longer a free parameter and has to be about $c/300$. Some further results which we have obtained can be summarized as follows:

(i) we obtain $z_{\mathrm{sep}} \sim 200$;

(ii) the interval in Ω which allows formation of galaxies with the observed parameters is $0.8 < \Omega < 1$.

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Ozernoy: Unfortunately the treatment of turbulent dissipation discussed by Drs Dallaporta and Lucchin is based upon very rough approximations for subsonic and supersonic dissipation. The conclusions reached differ significantly from our more careful approach. For example, as was mentioned in my talk, the constraints on vortex cosmologies are in fact more severe for small values of Ω, rather than for large values.

Steigman: In connection with the matter-antimatter annihilation models, problems arise because distortions of the spectrum of the microwave background radiation are expected as was discussed this morning by Dr Zel'dovich. So much energy has to be dumped into the Universe at redshifts of 10^3 to 10^4 that Compton scattering produces distortions of the spectrum and there is not sufficient time to re-thermalise the radiation. More detailed calculations have been performed by myself, and Drs Jones, Ames and Peebles.

Seed Fluctuations

W. Kundt: It has been well-known since the work of Lifshitz (1946) that galaxies cannot form from thermal density fluctuations in the early universe via gravitational instability if one assumes that such fluctuations $\delta\varrho/\varrho$ obey $|\delta\varrho/\varrho| \ll 1$ on all scales. On the other hand, a density contrast of order unity on the scale of the light horizon, if realized at some time, will be realized at all subsequent times in the absence of dissipation, and does seem to offer an explanation of galaxy formation. Such a density contrast of order unity on the horizon scale could have been established at time $t = 10^{-23}$ s in that strong interactions help gravity to form 'grains' from a heretofore maximally homogeneous cosmic matter density; see Carlitz *et al.* (1973), and also Kundt (1973). These heavy grains would have a mass of order 10^{15} g at formation, and an uncertain decay time of the order of a year or longer (due to the combined action of gravity and strong interactions) which defines the duration of the hadron era. They would form a collision-free (and hence inviscid), marginally relativistic gas.

More explicitly, the following mechanism is suggested for the growth of seed (density) fluctuations in the early universe: At $t = 10^{-23}$ s, matter 'tears' into heavy grains, one on average on the scale of the light horizon. The existence of particles means a destruction of (fine-grained) homogeneity, i.e. a density contrast which is of order unity within the light horizon at formation. Within the horizon, $\delta\varrho/\varrho$ can never exceed order unity due to causality restrictions. It is important however that in the absence of viscosity, a horizon contrast of order unity will most likely grow in scale such that it stays of order unity (on the growing horizon scale) for all times. A way to see this is to consider a fixed astronomical mass scale M. At very early times, M will encompass a huge number of horizon masses M_H, hence relative fluctuations on the scale M will be due to surface fluctuations, i.e. of order $|\delta\varrho/\varrho| = (M_H/M)^{2/3} \ll 1$. The growth law of small perturbations may thus be applied, and yields $|\delta\varrho/\varrho| \approx 1$ at the time when M enters the horizon (both for a matter-dominated, and for a radiationdominated Einstein-de Sitter universe; c.f. Lifshitz (1946), Kundt (1971), Carlitz *et al.* (1973)). For consistency it can be checked that the mean square gravitational random accelerations $g := (\langle g^2 \rangle)^{1/2}$ are of order $gt/c \approx \langle \delta\varrho/\varrho \rangle$ (where $\langle\ \rangle$ stands for the appropriate stochastic averaging along the past light cone), so that relativistic random velocities are created by a horizon contrast of order unity; c.f. Kundt (1973).

What is the fate of such primordial fluctuations (if they exist)? Their growth stops at the end of the decay of the heavy grains, due to viscosity, (perhaps at t = some years). At this time, which is the beginning of the radiation era, turbulent viscosity gives rise to a dissipation of random motions whose e-folding time is comparable with the cosmic time scale. As discussed by Silk at this Symposium, viscosity damps adiabatic density fluctuations exponentially below a significant level. However, a significant amount of density fluctuations would go into isothermal modes because in our model, entropy production means primarily production of photons, whose rate is proportional to the square of the (electron) number density n: $\dot{s} \propto n^2$. As a result, (electron density) waves with constant entropy density s transform into waves with $s \neq$ const, i.e. create isothermal components. The latter survive the radiation era, and act as seed fluctuations for galaxy formation after recombination (of the cosmic plasma).

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McCrea: Can the concept of light cones have any meaning at such early times as 10^{-23} s?

Kundt: Present unquantised General Relativity claims applicability for mass densities ϱ and times t satisfying $\varrho t^4 > \hbar c^{-5}$. The concepts of particle physics should be applicable for $t > \hbar/m_\pi c^2 \approx 10^{-23}$ s.

Bardeen: A problem with this picture is that large density perturbations $\delta\varrho/\varrho \sim 1$ would give rise to large numbers of black holes.

Kundt: Quantum field theory forbids you having zero clumpiness. Density contrasts $\delta\varrho/\varrho > 1$ would be marginally excluded by causality requirements.

Icke: If we change the equation of state of the gas we might obtain a phase transition which could give rise to significant seed fluctuations.

Kundt: Yes, but to our knowledge only on scales which are small compared with the horizon, unless such a phase transition happens at $t \approx 10^{-23}$ s.

Silk: It is worth noting that just such a phase transition is found in the theory of Prof. Layser in which the Universe is initially cold. There is a phase transition between solid grains of hydrogen and the vapour state and he argues that fluctuations originate in this way.

Formation of Galaxies and Clusters of Galaxies by Self-Similar Gravitational Condensation

W. H. Press and P. Schechter: We consider an expanding Friedmann cosmology containing a ‘gas’ of self-gravitating masses. The masses condense into aggregates which (when sufficiently bound) we identify as single particles of a larger mass. We propose that after this process has proceeded through several scales, the mass spectrum of condensations becomes ‘self-similar’ and independent of the spectrum initially assumed. Some details of the self-similar distribution, and its evolution in time, can be calculated with the linear perturbation theory. Unlike other authors, we make no *ad hoc* assumptions about the spectrum of long-wavelength initial perturbations: the nonlinear N-body interactions of the mass points randomize their positions and generate a perturbation to all larger scales; this should fix the self-similar distribution almost uniquely. The results of numerical experiments on 1000 bodies appear to show new nonlinear effects: condensations can ‘bootstrap’ their way up in size faster than the linear theory predicts. The self-similar model predicts relations between the masses and radii of galaxies and clusters of galaxies, as well as their mass spectra. We compare the predictions to available data, and find some rather striking agreements. If the model is to explain galaxies, isothermal ‘seed’ masses of 3×10^7 to $3\times10^9 M_\odot$ must have existed at recombination. To explain clusters of galaxies, the only necessary seeds are the galaxies themselves. Our numerical results support a growth of condensation mass with expansion factor of $M\propto R^2$.

Zel’dovich: The conjecture that condensation is a cascade process has a long history (see, for example, Layser’s work). Fourier methods should be used. If the initial distribution of the point masses is purely random i.e. a Poisson type spectrum, $\Delta N/N=N^{-1/2}$ which corresponds to a flat spectrum $n_k=k^0$ where n_k is the density Fourier component for wave vector k. $\delta_k=(n_k^2k^3)^{1/2}=k^{3/2}=\lambda^{-3/2}=V^{-1/2}$ is just the same as $\Delta N/N\propto N^{-1/2}\sim V^{-1/2}$ where $\lambda=1/k$ is the wavelength and $V=\lambda^3$ is the effective volume. Perturbations on different scales grow independently like $t^{2/3}=$ $=(1+z)^{-1}=a(t)$. Therefore the condition $\Delta N/N=1$ gives $N^{-1/2}a(t)$ const$=1$, $N\sim M\propto a^2(t)$ which is the explanation of Press’s result and is indeed well known to him. No cascade is involved but only the initial spectrum.

But if we assume that there is a cut-off to the initial perturbation spectrum at $k<k_{\rm min}$, $\lambda>\lambda_{\rm max}$, and $M>M_{\rm max}$, only bodies with $M<M_{\rm max}$ are formed initially. Of course encounters among these condensations give rise to the creation of larger scale perturbations. But the encounters are subject to mass conservation, $\int n\,{\rm d}V=$const and momentum conservation $\int vn\,{\rm d}V=$const. The perturbation of density begins with $\int x^2n\,{\rm d}V$ which corresponds to the Fourier transform $n_k\propto k^2$, $\delta_k=k^{7/2}=V^{-7/6}$. Therefore I think that the condition $N^{-7/6}a(t)$ const$=1$ leads to the ultimate growth law $N\sim M\propto a^{6/7}(t)$. A bet is made with Press (a bottle of White Horse against a bottle of Stolichnaya) that the exponent is $\frac{6}{7}<\frac{3}{2}$ (Zel’dovich) or $2>\frac{3}{2}$ (Press).

Afterthought: I visualised short range encounters. Should not the long-range nature of the encounters lead to the victory of Press over me?

Ames: If clusters form from the aggregation of mass points and galaxies formed at a redshift of about 20, then the clusters must have been touching or overlapping at that time. Therefore the cells of point masses must have been interacting and their positions must not have been uncorrelated.

Chernin: I would like to draw attention to a classical result due to Kolmogorov on the statistical properties of the fragmentation of vortices. He showed that the distribution of parameters such as their masses is logarithmically gaussian. This result depends only on the assumption that the decay probability is the same on all mass scales. It would be interesting to compare this prediction with the observed mass distribution of galaxies.

Relaxing Clusters in the Evolving Universe

G. Paal: Characteristic sizes for the bright cores of 34 rich clusters of galaxies have been determined according to the definition published earlier (Paal, G.: 1971, *Astrofizika* **7**, 435). 30 of them lie in the range of redshift $0<z<0.2$ and Sandage gives photoelectric magnitudes and redshifts for them (1972, *Astrophys. J.* **178**, 1). It is well known that the apparent brightness, 1, the angular size, θ and redshift are related by the following equation:

$$SB=\frac{1}{\pi\theta^2}\ \frac{L}{\pi D^2}(1+z)^{-4}, \tag{1}$$

where SB means 'surface brightness', L is the 'luminosity', and D is the linear diameter. This formula holds true for any spacetime (1966, *Astrophys. J.* **143**, 379). My 'surface brightness' is obtained by dividing the apparent brightest 1 of the first ranked cluster *galaxies* by the area of the *cores* of *clusters.*

In a static 'tired light' cosmological model we should have -1 in the exponent of Equation (1). (See Geller, M. J. and Peebles, P. J. E.: 1972, *Astrophys. J.* **174**, 1).

My principal result is that contrary to Equation (1):

$$\log\frac{SB}{SB_0}=-9.1\log(1+z)-7.4, \tag{2}$$

where $SB_0=l_0/\pi$, l_0 is defined by $m=-2.5\log(l/l_0)$, and m is Sandage's magnitude (see Figure 1).

According to both theory and observation the absolute magnitude of the brightest galaxies in clusters cannot change by more than one magnitude over the range of redshifts covered by the observations, and therefore the observed change of SB must be due to the changes of D with epoch. In this case the Figure and Equation (2) lead to the following conclusions:

(i) The observed part of the Universe is rapidly expanding relative to the bright cores of rich clusters of galaxies (in the range $0<z<0.2$ only!). This statement does not depend on the cosmological model or the nature of redshift and it passes a significance test even at the 0.0001 significance level.

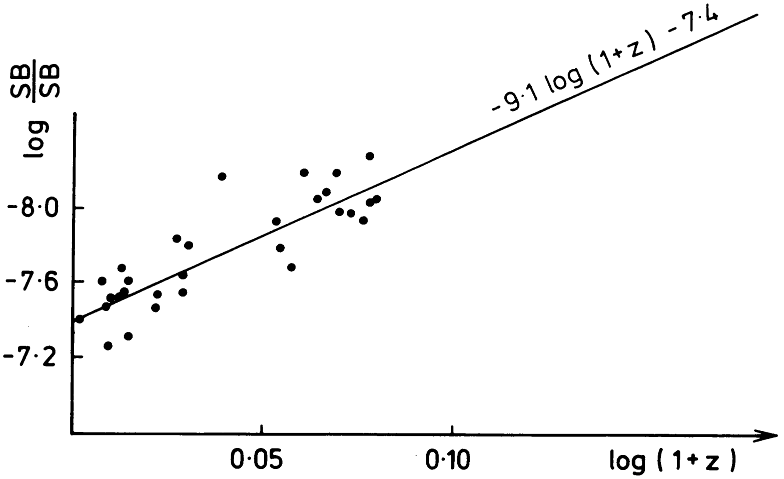


Fig. 1.

(ii) The bright cores of rich clusters are contracting (significant at the 0.001 level). In an expanding universe the indicated contraction rate is about 60% in 2×10^9 yr. A contraction less than 30% has a probability of about 0.02. Computer simulations of clusters of galaxies show that in a gravitationally bound cluster the core can contract this much by relaxation in 1 or 2 crossing time (1972, *Astrophys. J.* **172**, 17), which is given by

$$t_{cr} \simeq 1.3\times10^{10}\left(\frac{R^3}{M}\right)^{1/2}\ \text{yr}, \tag{3}$$

where R is the harmonic mean radius of the whole cluster and M is its total mass expressed in units of 1 Mpc and $10^{13}\,M_\odot$ respectively. $R\approx1$ is a typical value for rich clusters. Supposing that the 'virial mass', $M_v\gtrsim10^{15}\,M_\odot$, is really present in rich clusters in the form of *discrete bodies* with masses typical for *galaxies* one gets $t_{\text{cr}}\lesssim1.3\times10^9$ yr in fair agreement with Equation (2) and its consequences. On the other hand putting into Equation (3) the optically derived 'number mass', $M_n\lesssim$ $\lesssim10^{14}\,M_\odot$, one obtains $t_{\text{cr}}\gtrsim4\times10^9$ yr which is hard to reconcile with the same data. If it is supposed that 'dark matter' is present, but distributed continuously the relaxation process should slow down by about two orders of magnitude (Dr S. J. Aarseth – private communication) in drastic disagreement with what has been observed. This probable 'rediscovery' of the missing mass and the much more definite exclusion of continuous dark matter are independent of the nature of the redshift dispersion in clusters.

(iii) In a static universe with a hypothetical progressive reddening of 'tired light' as the cause of the redshift, the rich clusters ought to have had twice as large cores as are observed 2×10^9 yr ago, which seems to be incompatible even with the supposition of the fastest possible relaxation caused by huge discrete bodies of dark matter (inside or outside the luminous galaxies).

The present investigation illustrates a new method of examining the nature of different redshifts and testing the evolution of the universe without presupposing a world model.

Schmidt: It is difficult to exclude systematic errors when measuring distant clusters.

Paal: I agree. A careful discussion of the measuring procedure and its possible errors is given in my paper in Astrofizica already referred to but since publishing that paper I have got several independent checks of the reliability of the measured angular sizes by comparing them with diameters defined in another way. They have been obtained from different counts made by different observers working with different telescopes and also by comparing the details of the θ-z relation with what is expected on the basis of Sandage's Hubble sequence as proposed in my earlier paper. I emphasise that what is important is that this is a new and powerful method of testing the expansion and evolution of the Universe, the evolution of clusters of galaxies and the existence and distribution of the missing mass in them without recourse to hypotheses as to the interpretation of redshifts and redshift dispersions.

Karachentsev: I should like to report some preliminary results concerning the distribution of cluster centres obtained recently at the Special Astrophysical Observatory. Taking as a basis Abell's catalogue of rich clusters of galaxies, we counted $n(x)$, the number of cluster centres inside a ring of radius x around each cluster and $n'(x)$ the number of centres around 'empty', randomly chosen origins. The analysis was restricted to galactic latitudes greater than 30°. We calculated the mathematical expectation of the number of physical neighbours of a cluster, $E(K(x))$ which may be expressed as

$$E(K(x)) = E(n(x)) - E(n'(x)),$$

where $E(n(x))$ and $E(n'(x))$ are the expectations of the corresponding random distributions. Obviously we may consider n' and K as independent random values. Similarly it is easy to derive the expression for the dispersion of $K(x)$

$$D(K(x)) = D(n(x)) - D(n'(x)).$$

Such a method was proposed by Prof. Neyman and independently by Dr Fessenko.

We divided Abell's clusters into distance classes '1+2+3+4', '5', and '6'. We obtained the following results.

(1) Choosing the 'empty' random origins according to a Poisson distribution, we find for distance class '6' clusters

$$E(K_{\text{‘}6,\,6\text{’}}(x=3°)) \simeq 4 \pm 0.5.$$

It should be noted that $E(K(x))$ is the *integral* average number of physical neighbours inside a ring of radius x deg. This estimate of K is in good agreement with previous estimates of the average population of superclusters (Abell, 1959; Kiang, 1966; Karachentsev, 1966). The tail on the function $E(K(x))$ for $x > 3°$ may be caused by large scale gradients in Abell's catalogue or by interstellar obscuration of light.

(2) Our second choice of the 'empty' origins was shifting the origin of the counts by

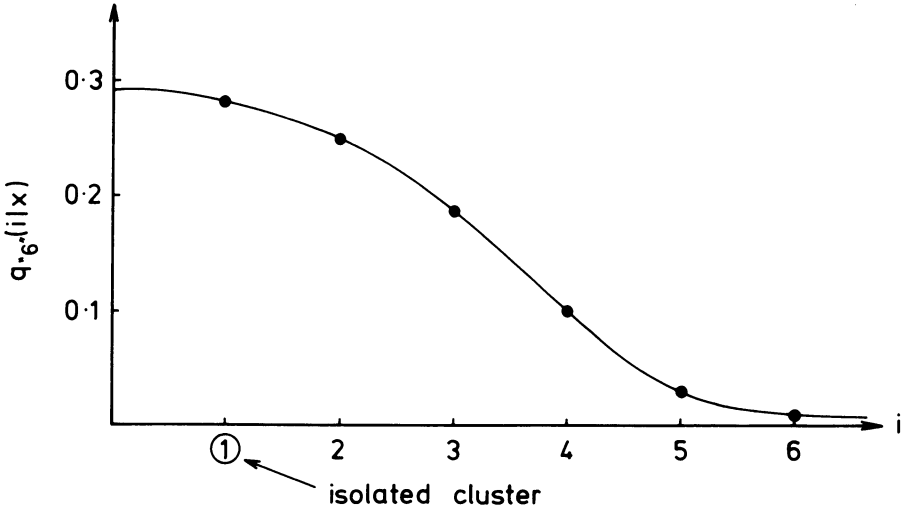
$\Delta\alpha = 6°$ from the initial cluster centres. We found that

$$E(K_{\text{‘}6,\,6\text{’}}(x \rightarrow \infty)) = 2 \pm 0.3$$

and for the number of clusters with distance class ‘6’ around those of distance class ‘4’

$$E(K_{\text{‘}6,\,4\text{’}}(x)) \simeq 0.$$

(3) We also obtained $p(i)$, the probability that an arbitrarily chosen cluster belongs to a physical system with population equal to i (see Figure 2). x is the radius of the supercluster in projection onto the celestial sphere. So our principal conclusion is that only half of the previously detected clustering effect may be caused by real physical associations of cluster centres.



Kiang: Dr Karachentsev has just shown that the mean number of clusters of galaxies in a supercluster is about 4 and mentioned the fact that the same result was obtained by me in 1967 (*Monthly Notices Roy. Astron. Soc.* **135**, 1) by a different method. Now, in the same paper I was able to estimate the characteristic linear dimension of a supercluster to be about 96 Mpc (with $H = 100$ km s^{-1} Mpc^{-1}). This is such a large fraction of the mean distance between the centres of superclusters that superclusters must interlock strongly. That the same sort of thing happens with the first-order clusters of galaxies has been pointed out long ago by Neyman and Scott (1953, *Proc. Nat. Acad. Sci. U.S.A.* **39**, 737). Now clustering, whether on a few discrete scales or on a continuum of scales, destroys the simple kind of homogeneity that most theoretical cosmologists cherish but, with interlocking, things may not be so bad after all for then clustering on all scales may well be consistent with the existence of a mean number-density of galaxies valid for all sizes of sample volumes.

Partridge: Since the title of our meeting is the ‘Confrontation of Cosmological Theories with Observational Data’, let me briefly mention some tentative observational results which may be of use to theoreticians.

There are essentially two approaches to the question of galaxy formation – to work forward from initial conditions, or to work backwards in time from the present properties of galaxies. Most of the papers presented today have taken the former approach. Weymann (1967) and Peebles and I (1967) have taken the other approach: given the present properties of galaxies, what must they have been like when they first formed?

The major result is that the initial luminosity of young galaxies is much larger than the present luminosity:

$$L_i/L_p \sim 100\text{–}1000 .$$

Recently, Davis and Wilkinson (1974) and I (1974) have separately searched for young galaxies of this type in a wide spectral region from the blue to the near infrared. Both photographic and photoelectric techniques were empoyed.

The *tentative* results indicate that galaxies of this sort must form at epochs *before* the epoch corresponding to

$$z(t_f) + 1 \geqslant 7 .$$

If galaxies form later, at $z + 1 \leqslant 7$, then the initial bright period suggested by Weymann and Peebles and Partridge must be less striking than assumed.

Note that the tentative limit excludes $z + 1 \sim 3.5$, an epoch suggested for quasar and radio galaxy formation.

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Ozernoy: Dr Weymann in an unpublished paper reached conclusions similar to those just mentioned by Dr Partridge. The total luminosity of all young galaxies contradicts the upper limit to the optical background radiation of Roach and Smith unless the birth of galaxies occurs at redshifts as large as 10 or more. This raises difficulties with the 'pancake' model of primordial inhomogeneities as I mentioned a few minutes ago.

Schmidt: Concerning the epoch of formation of quasars, it has looked for some time as if their density does not increase beyond $z = 2.5$. We have now seen some quasars with rather larger redshifts. There are some indications but they are still very weak that the redshift at which the quasar density does not increase any more may be greater for the brightest quasars than for those of average luminosity.

Zel'dovich: If quasars as luminous as 3C 273 existed at a redshift of 6 and there was neutral hydrogen absorption between the quasar and us, would it be possible to detect them?

Schmidt: It would be very difficult since there would be no emission in the visual region to the short wavelength side of 8400 Å.

Zel'dovich: And if there were no neutral hydrogen absorption?

Schmidt: Yes, it would be possible. To take another example, PHL 957 has V magnitude 16.7 and a redshift 2.7. The spectrum could still be measured if such an object had $V=19$ which it would have if it were three times as far away (assuming a spectrum $S \propto \nu^{-1}$). In a $q_0=1$ universe this would correspond to a redshift of 7.

It is also interesting that Dr Oke has found that the spectra of the two quasars with the largest redshifts are rather different. OH 471 has a redshift of 3.4 and the continuum essentially goes to zero beyond the Lyman limit. OQ 172 has a redshift 3.53 but there is no absorption at the Lyman limit. In fact no discontinuity at the position of the Lyman limit has been seen at all.

Zel'dovich: Does this prove that there are clouds of neutral hydrogen?

Oke: It should be noted that these quasars with the largest redshifts are not intrinsically brighter than the brightest quasars which we have seen before.

Rees: The interesting question has been raised of the relation between the epochs of formation of galaxies and quasars. The evidence would seem to be consistent with a picture in which galaxies are formed at a redshift z greater than 7 and the quasars form much later. This poses problems for models in which quasars are supposed to be the precursors of galaxies.

Wagoner: The fact that the chemical abundances of quasars are not wildly different from normal forces us to believe that the galaxies must have formed first before the quasars.

Scheuer: I do not think that we can yet be sure that the numbers of quasars do not go on increasing to quite large redshifts. The evidence indicating that the quasar numbers peak at $z=3$ depends chiefly on quasi-stellar radio sources, either directly (e.g. Longair's work) or at least through the finding of the sources (e.g. Schmidt's work). At large redshifts the microwave background energy density was much greater than now and the lifetime of the radio sources could well be drastically reduced as fast electrons lose more energy by Compton scattering. The cut-off in the optical spectrum which has been reported for one of the quasars at $z=3.5$ indicates that we may also be missing many quasars with large redshifts because they can be observed only in the extreme red end of the optical range.

Thus it is still possible to imagine that Partridge's young galaxies are quasars and that the apparent scarcity of quasars at very large redshifts is a kind of selection effect.

Schmidt: Dr Scheuer is correct that most of the information comes from radio quasars and that we may lose them at large redshifts. We must therefore find them optically. There is however the problem of absorption mentioned by Dr Scheuer and the fact that the UV excess disappears for such large redshift objects. Only in a few cases will the UV excess technique for finding quasars at large redshifts be effective. OQ 172 is such a case.

Gogolewski: One may be able to use large space telescopes working in the infra-red region of the spectrum to find quasars with large redshifts and also to identify the unidentified radio sources, some of which may be very large redshift quasars.

Schmidt: The infra-red colours of quasars do not stand out against those of stars in our own Galaxy. We are in danger of going back to the situation of the 1950s when quasars were not found because they did not stand out.