THE PROBLEMS OF COSMOLOGY

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The business of modern cosmology is the search for the main constituents of the universe, the pattern of their distribution and motion, the relation to the geometry of space-time, and the way the whole arrangement is evolving with time. This leads us to a rich list of research problems. I describe here three examples that illustrate the expected role of space telescope in the endeavour.

I. THE DISTRIBUTION OF GLOBULAR STAR CLUSTERS

In Ostriker's (1977) cannibalism scenario giant elliptical galaxies grow by capturing neighbors. If the growth by capture and violent relaxation had proceeded through several generations it would have tended to produce a fixed ratio of globular clusters to starlight. This is not observed in the Virgo cluster: the galaxy M87 has an unusually large abundance of clusters for its luminosity in comparison to other large ellipticals (Harris and Petrie 1978). The distribution of clusters within M87 is similar to the distribution of starlight at $\theta \lesssim 20'$, corresponding to $r \lesssim 100$ kpc (Harris and Smith 1976). It would be of considerable interest to know whether the halo of light extending beyond 20' around M87 is matched by a similar halo of globular star clusters.

A test from the ground is not practical because of the problem of telling the globular clusters from the foreground stars and background galaxies. Space telescope observations will readily settle the question because the clusters will be resolved ($\theta \sim 0.3''$). If clusters are not present in the extended halos of giant ellipticals and cD galaxies we will have the interesting puzzle of understanding how a sea of stars spread through the halo without bringing clusters with it. The mass-to-light ratio of the matter in halos is thought to be consideraly larger than in the central parts of galaxies, as is

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required to account for the remarkably flat rotation curves in some spirals and the dynamics of groups and clusters of galaxies (eg. Ostriker, Peebles and Yahil 1974; Rubin 1979). If globular clusters were distributed in proportion to mass the abundance of clusters relative to starlight would increase going into the halo. That does not happen in our galaxy, but it is a single and perhaps not representative case. With space telescope observations it should be possible to determine the general pattern of the distribution of globular clusters around spiral and elliptical galaxies and then decide whether a similar pattern in the mass distribution could account for the dynamics of galaxy pairs, groups and clusters.

Could intergalactic globular clusters be common (Peebles and Dicke 1968)? We know from limits on the possible contribution to the light of the night sky that the mean luminosity density due to clusters could not exceed about 10^8 $L_\odot$ Mpc^{-3}, comparable to that of galaxies (Dube, Wickes and Wilkinson 1977). With $M_V \sim -8$ this gives space density $n \lesssim 10^3$ Mpc^{-3}. At 1 Mpc a cluster diameter is ~5'', large enough to be measured from the ground but perhaps not so large that one could tell it from a distant galaxy without special study. Thus local surveys for globular clusters do not much improve the limit on n. In a 3' by 3' space telescope field the above space density gives ~10 globular clusters at distances $\lesssim$ 40 Mpc, diameters $\gtrsim$ 0.2'', $J \lesssim 25$, to be compared to ~100 galaxies at the same limiting magnitude (Kron 1978; Tyson and Jarvis 1979). The space telescope thus will considerably improve the tests for intergalactic globular clusters.

2. TESTS OF THE EXPANSION OF THE UNIVERSE

The general expansion of the universe is a key element of the conventional cosmology. We have strong indirect evidence of expansion from the observation that the microwave background has a spectrum close to blackbody. More direct local tests for the kinematic effects of expansion have been proposed and are well worth pursuing. Tammann (1979) noted that under the expansion hypothesis the redshift factor applies not only to the frequency of radiation but also to the observed rate of a distant event, which would not be expected in a tired light cosmology. Thus under the expansion hypothesis the light curve of a supernova observed at redshift z should have a time scale larger by the factor 1 + z than that of a supernova of the same type occuring nearby. Tammann points out that with the space telescope it may be possible to detect distant supernova and apply this test.

In an expanding cosmology the bolometric surface brightness of a galaxy varies with redshift as

$$i \propto (1 + z)^{-4} \; . \qquad (1)$$

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One power of 1 + z comes from the reduced energy of each photon, one from the reduced rate of reception of photons, the remaining two from aberration. In a tired light cosmology one might expect only the first effect and so the relation

$$i \propto (1 + z)^{-1} . \tag{2}$$

It will be noted that these relations are independent of space curvature. Their use as a test of the expansion hypothesis was first discussed by Hubble and Tolman (1935), and the test was revived by Geller and Peebles (1972). The main observational problem is fixing the relative angular scales at which surface brightnesses of the galaxies at different redshifts are to be compared (eg. Hoffman and Crane 1977). The greatly improved angular resolution provided by the space telescope should give much more reliable measures of galaxy core radii (if they exist) and so a much better test for expansion.

A third possible test is based on galaxy counts as a function of apparent magnitude. If the universe is homogeneous we have the Robertson-Walker line element

$$ds^2 = dt^2 - \frac{a^2 dr^2}{1 - r^2 R^{-2}} - a^2 r^2 d\Omega, \tag{3}$$

where R^{-2} is a constant. In the expanding cosmology the redshift factor is

$$1 + z = a_o/a(t), \tag{4}$$

the expansion factor a(t) is written as the series

$$a(t) = a_o[1 + H(t-t_o) - \tfrac{1}{2}q_o\, H^2(t-t_o)^2 + \ldots], \tag{5}$$

and, if $\Lambda = 0$, the density parameter and space curvature parameter are

$$\begin{aligned} 2q_o &= \Omega = 8\pi G\rho/3H^2, \\ (a_oR)^{-2} &= H^2(\Omega-1). \end{aligned} \tag{6}$$

For purposes of comparison let us consider a tired light model with a = constant in equation (3) and redshift proportional to distance,

$$d\nu = -\nu H dt \quad , \quad \nu \propto e^{-Ht} \quad . \tag{7}$$

In these two models we can write the expected count of galaxies as a function of bolometric flux in the series expansion

$$\frac{dN}{df} = \Sigma \frac{n}{2} \frac{L^{3/2}}{f^{5/2}} \left[1 - \alpha \left(\frac{H^2 L}{f}\right)^{1/2} + \beta \frac{H^2 L}{f} + \ldots\right] . \tag{8}$$

The sum is over the luminosity function, with L the galaxy luminosity per steradian. In the expanding model the first two coefficients in the series are

$$\begin{aligned} \alpha &= 4 \\ \beta &= \frac{25}{2} - \frac{5q_o}{2} + \frac{1}{2H^2 a_o^2 R^2} \end{aligned} \quad . \tag{9}$$

In the tired light model we have

$$\begin{aligned} \alpha &= 2 \\ \beta &= \frac{25}{8} + \frac{1}{2H^2 R^2} \end{aligned} \quad . \tag{10}$$

The coefficient α is independent of the parameters in the model and so galaxy counts at $z < < 1$ are not very sensitive as a discriminant among Friedman-Lemaitre models (Sandage 1961). That is an advantage in the test for expansion because it means the adjustable parameters are not very important. For a meaningful application of the test we would need tight control on the distribution of K-corrections from color measurements of a fair sample of the galaxies, and a reliable luminosity function from a fair sample of galaxy redshifts. Here what is needed is not space telescope but rather considerable ground-based labor. It remains to be seen whether luminosity evolution might spoil the test.

3. THE CLASSICAL COSMOLOGICAL TESTS

The theory and practice of tests meant to discriminate among Friedmann-Lemaitre models has been discussed by Sandage (1961), Gunn (1978) and other practitioners. I review here some theoretical considerations relevant to possible observations at redshifts on the order of unity.

We extract two relevant lengths from equations (3) and (4). The proper circumference of the circle described by a great circle at fixed redshift z is

$$C(z) = 2\pi a(t) r(z) . \tag{11}$$

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A comoving observer sees that a light pulse travelling toward us moves distance dt in the interval of cosmic time t to t + dt, and that distance is related to the difference of redshifts at the two events by the equation

$$dt = dz/\left[(\dot{a}/a)(1+z)\right] . \tag{12}$$

The angular size of an object with proper size d seen at redshift z is

$$\theta = 2\pi d/C(z). \tag{13}$$

In a Friedmann-Lemaitre model with $\Lambda = 0$ the ratio of expected values of θ with $\Omega = 1$ and $\Omega = 0.1$ is

$$\begin{aligned}\theta(\Omega = 1)/\theta(\Omega = 0.1) &= 1.12, \quad z = 0.5;\\ &= 1.24, \quad z = 1.0.\end{aligned} \tag{14}$$

Thus an interesting measure of Ω from observations at $z \sim 1$ requires that the systematic error in d (relative to objects at low redshift) be much less than 25 percent.

If the mass distribution is clumpy it causes fluctuations in the value of θ at fixed d and z, depending on how the tidal fields of the clumps near the line of sight affect the convergence of the light rays (eg. Dyer and Roeder 1974). However, the mean value of θ^2 is not affected because the mean solid angle per source, which is 4π divided by the number of objects in the sky, is unaffected (Weinberg 1976). If a sample of objects with small enough scatter in d were available the scatter in θ at fixed z would be an interesting measure of mass clumping (eg. Press and Gunn 1973), and we would learn even more if we had the scatter in angular sizes both for galaxies and clusters of galaxies.

The measured energy flux from a galaxy, integrated over frequencies, varies with redshift as

$$f \propto C(z)^{-2}(1 + z)^{-4}. \tag{15}$$

The first factor fixes the solid angle (eq. [13]), the second factor the surface brightness (eq. [1]). Although the redshift-magnitude (z-m) test is equivalent to the z-θ test (in expanding cosmologies) the former has the advantage that C(z) appears squared, and perhaps also that f is easier to measure than θ. We see from equations (14) that an interesting measure of Ω from observations at $z \sim 1$ requires that systematic errors of luminosities of distant galaxies relative

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to nearby ones be much less than 50 percent, $\delta\langle M\rangle \ll 0.5$ magnitudes. The expected amount of evolution of M is discussed at this meeting by Tinsley.

The final test is based on counts of objects. The distribution in redshift and magnitude for objects with luminosity function Φ is (eqs. [11] and [12])

$$\frac{\partial^2 N}{\partial z \partial m} = \frac{C(z)^2(1+z)^2}{4\pi^2(\dot{a}/a)} \Sigma \frac{d\Phi}{dM}(\text{type; } M=m-g(z,\text{type})). \tag{16}$$

The function g represents the redshift-magnitude relation with the K-correction appropriate to a particular spectral type. If $d\Phi/dM$ is fairly narrow we have two tests for Ω. The first is the variation with m of the shape of the distribution in redshift: the z-m relation. The second is the variation in the number of objects with z, which is fixed by the factor in front of the sum. If $\Lambda = 0$ the ratio of this factor in models with $\Omega = 1$ and $\Omega = 0.1$ is

$$\frac{C^2 a/\dot{a}(\Omega = 1.0)}{C^2 a/\dot{a}(\Omega = 0.1)} \begin{matrix} = 0.67, & z = 0.5; \\ = 0.48, & z = 1.0. \end{matrix} \tag{17}$$

For a useful test of Ω from counts at $z \sim 1$ we would have to be sure that the comoving density of objects agrees with the local density to much better than a factor to two.

The integral of equation (16) over z yields the count-magnitude relation. At low z this N-m relation is insensitive to the parameters of the cosmological model (eq. [9]), but that is not a problem at $z \sim 1$ where the sensitivity becomes comparable to that of the other tests. The great virtue of the N-m test is that m is much easier to measure than z so the measurements can probe considerably deeper. Galaxies with redshifts on the order of unity are just about within reach of ground-based counts and well within the range of the space telescope.

The greatly improved angular resolution afforded by the space telescope may be of critical importance in helping us decide whether galaxies or clusters of galaxies might have held their shapes to much better than 25 percent accuracy since z = 1 and so might be useful standard lengths for the z-θ test. The possible stability of galaxies as standard candles for the z-m test has been a subject of some discussion, as is summarized by Tinsley at this conference. Again, observations of the color and appearance of galaxies at $z \sim 1$ may be expected to play an important role in the debate. The easiest observation is the N-m relation, and it will be of considerable interest to see how this goes at the depths reached by space telescope. A

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full interpretation likely will await the much more difficult observation of the joint distribution in z,m and color (eq. [16]). I have the impression that the main bottleneck will be the redshift measurements and that a second generation Faint Object Spectrograph sensitive to 1μ wavelength may play a decisive role in the development of the tests.

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APPENDIX

Dr Peebles provided participants with an outline-summary entitled "The Problems of Cosmology". This summary included an indication of how the various invited lectures contribute to different aspects of these problems. Because of its pedagogic value, it is reproduced below with Dr. Peeble's permission. The abbreviations are self-explanatory (e.g., g = ground, ST = Space Telescope, etc.).

The Problems of Cosmology

I. Z $\lesssim$ 0.3: THE LOCAL UNIVERSE

1. INVENTORY

 a. Galaxies

 - luminosity and morphology functions (Oemler)
 - physical and chemical nature and evolution (Oemler, Tinsley)

 b. Other objects

 - constraint on abundances of luminous objects: the integrated background in the radio, infrared, optical, uv, X-ray (g, rockets, balloons, COBE, IRAS, HEAO,...)
 - search for compact objects at $r \lesssim 100$ pc, $r_{core} \lesssim 10$ pc (ST)
 - distributions of compact galaxies, globular star clusters in clusters of galaxies (ST)
 - detecting massive dark objects in galaxies, clusters, the field (ST, ?)
 - intergalactic HI, HII clouds (g, IUE, HEAO; Bahcall)
 - other fossils: quasars, microwave background, extragalactic cosmic rays, quarks, magnetic monopoles, light and heavy neutrinos, other divers particles, magnetic fields, gravitational radiation, primaeval black holes, snowballs, goblins,...

2. CLUSTERING

 a. Clustering of galaxies on scales $\lesssim 10\ h^{-1}$ Mpc ($H = 100\ h$ km s^{-1} Mpc^{-1})

 - surveying in angular position and/or m and/or redshift: groups, clusters, cells, holes, filaments, hierarchies, clouds and superclusters (g)
 - evolution of clustering (ST)

b. Clustering on scales 10 h^{-1} Mpc $\lesssim r \lesssim cH^{-1}$ = 3000 h^{-1} Mpc

- isotropy of deep galaxy counts (g, ST)
- distribution of galaxies in angular position - redshift space (g)
- distributions of great clusters, quasars, radio sources (g, HEAO, ST)
- anisotropy of radiation backgrounds (g, COBE, HEAO).

3. THE MASS PROBLEM

a. Census of the local disc and halo

- main sequence stars, degenerate H stars at M $\lesssim$ 0.05 $M_\odot$ star remnants, interstellar matter (g, ST, HIPP; Salpeter, van den Bergh)

b. M/L of stellar populations (g, ST)

c. Dynamical measures of mass, M/L

- the structure of the Milky Way galaxy (van den Bergh, Oemler)
- velocity dispersions as functions of position in elliptical galaxies and in the bulges and halos of spirals (g)
- velocities of companions and satellites - galaxies, globular clusters, HI and HII regions (g)
- peculiar velocities derived from redshift statistics (g,ST)
- tests of the inverse square law (?)

4. THE GENERAL EXPANSION

a. Evidence of expansion: distinguishing the expected kinematics of expansion from predictions of tired light cosmologies

- $\delta\lambda/\lambda$ independent of λ (g,S)
- surface brightness $\propto (1 + Z)^{-4}$ (ST)
- timing $\propto (1 + Z)$ (g, ST)
- count-magnitude-redshift relations (g,ST)
- redshift $\propto$ distance (g, ST)

b. Time and distance scales

- astrometry (Tammann)
- Hubble's constant (Tammann)
- ages of galaxies, stars, the elements, the Solar System (Freeman, van den Bergh, Tinsley)

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5. OTHER PUZZLES

- black holes; matter-antimatter; matter creation and annihilation; variations of fundamental constants; unconventional redshifts; unconventional physics

II. $0.1 \lesssim Z \lesssim 3$: THE UNIVERSE NEAR THE HORIZON

1. EVOLUTION OF STRUCTURES

a. Galaxies

- color and magnitude: K-correlation, Scott effect and evolution (Tinsley)
- morphology: details at $Z \lesssim 0.3$, gross classification of the brightest galaxies at $Z \sim 1$ (ST)
- clustering: galaxy types, gas content, cluster morphology (HEAO, ST)

b. Quasars, blank field radio sources and beyond

- abundance as a function of Z; evolution
- clustering among themselves, around galaxies (Sargent), Bahcall, Longair)

2. THE CLASSICAL COSMOLOGICAL TESTS

- count-magnitude relation to $Z^* \sim 1$ to 2 (ST)
- count-angular size relation to $Z^* \sim 0.5$ to 1 (ST)
- redshift-magnitude relation for giant galaxies to $Z \sim 0.5$ (g, ST)
- redshift-count relation for great clusters to $Z \sim 0.5$ (g, ST)
- redshift distribution of galaxies by apparent magnitude (g, ST)

III. $Z \gtrsim 2$: THE YOUNG UNIVERSE

1. FORMATION OF GALAXIES, CLUSTERS

a. What does the sky look like at low surface brightness: spotty due to isolated compact protogalaxies ? mottled by overlapping diffuse protogalaxies ?

- radio: young active galaxies, quasars, HI clouds (g)
- microwave: irregularities present at decoupling; perturbations by intervening protogalaxies and protoclusters (g)

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- infrared: highly redshifted starlight if stars formed early (COBE, IRAS)
- optical: the light from galaxies at moderate redshift (g,S)
- uv: starlight from very active galaxies at moderate redshift (DUVS ?)
- X-ray: hot gas from collapsing protogalaxies and proto-clusters; active young objects; patchy intergalactic matter (HEAO)

b. Spectrum of the electromagnetic background

- microwave background: distortion from a Planck spectrum by departures from homogeneous isotropic expansion; absorption and emission by intervening matter (COBE)
- infrared - optical - uv - X-ray background: integrated light from early generations of objects (COBE, HEAO, S)

2. BEYOND THE FRINGE

a. Remnants of the Big Bang

- light element abundances (ST, S)
- quarks and beyond (?)

b. Origin of the Big Bang

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DISCUSSION

Baum: The two distant indicators, galaxy diameter and galaxy magnitude, used in classical cosmological tests are intimately linked with one another and are not easily separable. If the luminosity profiles of individual galaxies followed a simple power law $I = I_o r^{-n}$ with constant n, it would be impossible to distinguish a distant intrinsically bright galaxy from a nearer intrinsically faint one, and cosmology would be impossible. In the real world, n is not quite constant, and the ability to measure diameters and magnitudes correctly is dependent on that. But the luminosity profile of a galaxy departs only mildly from constant n within the portion of the profile that is feasible to measure at large distance, so in practice it is difficult to determine diameters and magnitudes correctly. Photometric imaging with the Space Telescope CCD cameras should make it possible to handle this problem better than in much earlier work.

Tinsley: The counts of faint galaxies by Richard Kron which extend to 24th magnitude disagree with the predictions of uniform world models. Thus, contrary to what might have been implied by Peebles, the counts of galaxies do not seem to be a particularly sensitive cosmological test for q_o.

Spinrad: There is a counter-argument to what Beatrice has just said. If one has colour information and if one believes models for the colour evolution of galaxies, one can take out the evolutionary changes and find a self-consistent solution for the age of the galaxies and q_o from the counts.

Tinsley: Kron tried to do this but was not successful.

Einasto (Discussion leader): One of the key problems of cosmology is the study the large-scale structure of the Universe. The comparison of the large scale structure at different redshifts gives us information about the physical processes which have led to the formation of this structure. In particular, it is possible to discriminate between different cosmogonic scenarios : gradual clustering of galaxies and clusters from smaller units or the formation of proto-superclusters first and galaxies thereafter as in the "pancake" theory.

The local large scale distribution of galaxies has been studied recently using large samples of redshifts (e.g. by Gregory, Thompson and Tifft; Tarenghi, Chincarini and Rood; Einasto, Joeveer and Saar). These studies have shown that galaxies and clusters are concentrated into cluster chains and more or less plane sheets in between - superclusters of galaxies.

Most of the cluster chains consist of poor clusters and consequently their detection at large redshifts is impossible as is the detection of

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sheets of galaxies. However, some chains, such as the Perseus chain of galaxies, are very rich and these can be detected at high redshifts and may be considered as supercluster indicators. The computer processed map of the Shane-Wirtanen counts of galaxies (Seldner, Peebles and collaborators) shows that at redshift $z \gtrsim 0.15$, cluster chains are clearly visible. Thus supercluster chains existed at a look-back time of ~ 3 G years.

To follow the evolution of the clustering over a longer period, cluster chains should be observed at larger redshifts. To reach $z \gtrsim 0.5$, galaxy counts to $m \gtrsim 20.5$ should be made; counts to $m \gtrsim 22$-23 give information about the structure at $z \gtrsim 1$. Galaxy counts can be made with ground-based wide field telescopes. Cluster redshifts can be measured with large ground-based telescopes using CCD detectors. Radio and X-ray data are also essential because all rich clusters contain radio galaxies and are extended X-ray sources. Detailed study of the morphology of galaxies in cluster chains can only be made with ST. Local rich clusters are very rich in elliptical and SO galaxies. It is of fundamental importance to follow the evolution of the morphology of galaxies in cluster chains.

Groth: We have a major industry in Princeton working out the statistical properties of the clustering of galaxies. We are now studying deeper samples of galaxies from deep plates taken with large ground-based telescopes and we realistically expect to study the clustering of galaxies with mean redshift $z \sim 0.4$. With ST, it is feasible to study the clustering at a mean redshift $z \gtrsim 1$. With a modest number of wide field camera frames, we should be able to obtain a sample of say, 1000, galaxies for statistical studies. We believe that the evolution of the clustering properties of galaxies on large scales with cosmic epoch should be easier to understand than the evolution of individual galaxies but we shall see.

N.A. Bahcall: The core radii of the galaxy distribution in rich compact clusters appear to be rather constant (Bahcall 1975. Ap. J., 198, 249, 1977. Ann. R. Astr. Astrophys., 15, 505). When measured for the brightest ~ 3 magnitude galaxies in a cluster, this size is found to be (Bahcall) 0.25 ± 0.05 Mpc ($H_0 = 50$). A somewhat larger value of typically ~ 0.4 Mpc is found by Dressler (1976 Ph.D. dissertation, Santa Cruz) for the distribution of much fainter galaxies. This is shown by Quintana (1979 A.J., 84, 15) and Sarazin (1979 preprint) to be partly due to a weak dependence on limiting magnitude of the measured core size. This relatively small spread in the core radius when measured in a consistent manner suggests that core radii of galaxy clusters may provide a standard-size for use in the angular-size-redshift cosmology test. The angular-size-redshift relation for a 0.25 Mpc radius is shown in the figure for two values of q_0: 0 and 1. The crosses are measurements by Bahcall (1975). The Wide-Field-Camera on Space Telescope can be used to measure core radii of clusters of galaxies at large redshifts, $z \simeq 0.5 - 2$,

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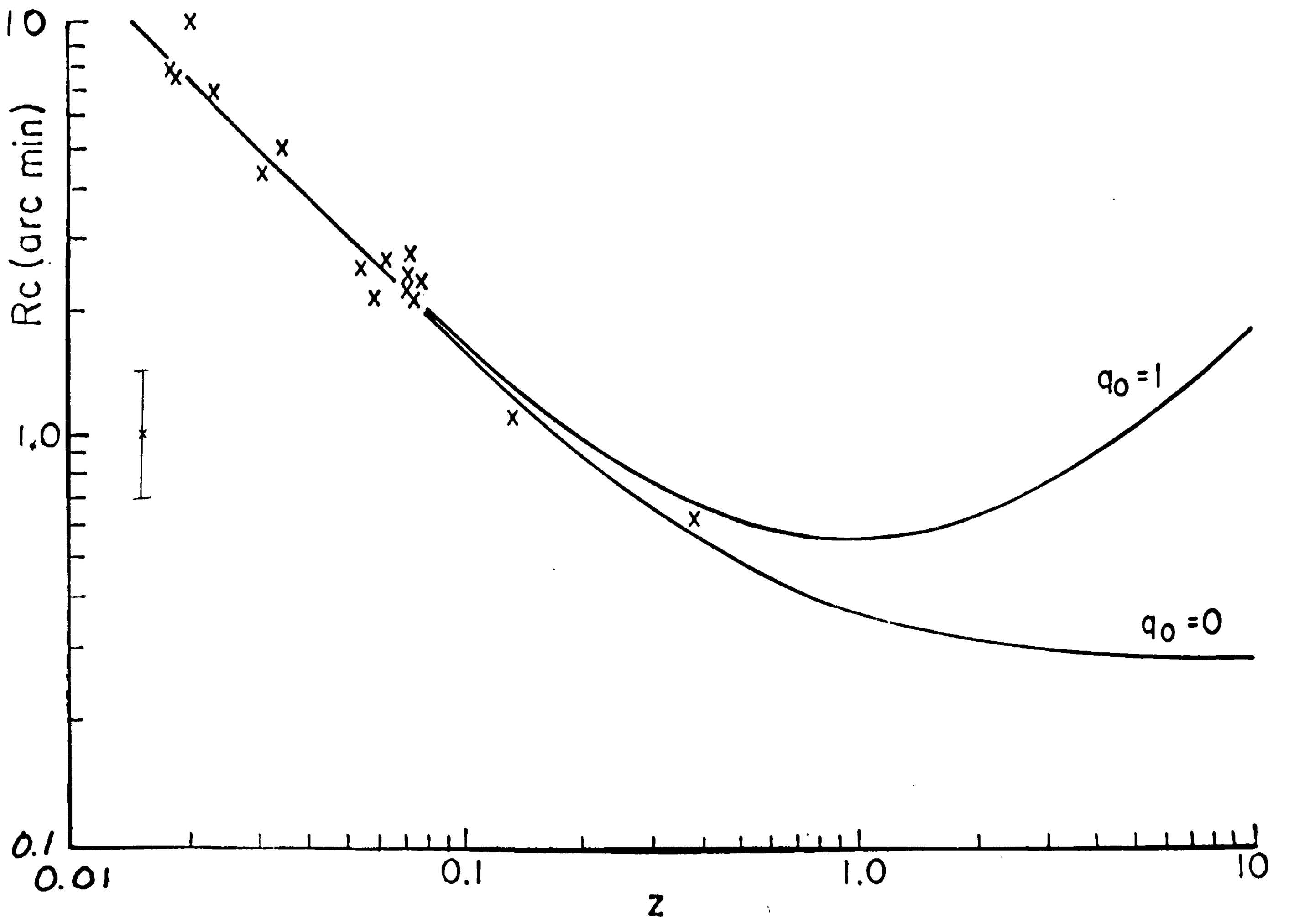

(R_c < 1' at z ≃ 0.5–2). At z ≃ 2, the difference between q_o = 0 and 1 models is a factor of two in measured angular size. This is a relatively large difference; a reasonable sample of distant clusters (∿ 10–20) may be exploited to set limits on q_o (assuming further work from the ground for z < 0.5 continues to show a relatively small spread in the core-size).

The evolution of core-size with epoch may be dominated by the dynamical evolution of the clusters. Additional observational information on the structure of the X-ray emitting intracluster gas and the galactic content of clusters at high redshifts would be helpful in calculating this evolution.

Spinrad: I want to address the question of the determination of the redshifts of normal galaxies at large redshifts. From the stellar content of a galaxy we observe absorption features and from the gaseous component various emission lines. Let me deal with the absorption spectra first.

In the standard optical spectrum of a galaxy, the main absorption features are the H and K lines of CaII, the 4000 Å break and the G band absorption feature. The optical spectrum has thus two characteristic breaks which enable redshifts from 0.2 to 0.6 to be determined. At larger redshifts, there are two main problems. First, I believe the stellar populations of galaxies evolve so that there are more hot stars in distant galaxies and this decreases the amplitudes of the breaks. Second, the features are shifted to long wavelengths. With the faint object spectrograph which cuts off at λ 7000 Å, it will be difficult to measure redshifts beyond z ≃ 0.8 using these features. It may be

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possible to measure redshifts using multi-filter photometry provided one has some confidence that one knows what the intrinsic spectra should look like.

At shorter wavelengths, there are discontinuities of larger amplitude in the Sun and F stars at λ 2900 Å and λ 2600 Å due to line blending. This should take one out to a redshift z $\approx$ 1. To measure larger redshifts, there is a silicon edge at 1600Å but for very large redshifts, one may have to use the Lyman limit at 912 Å. We do not know what this will look like. There is of course the problem that if you observe a spectrum with a single break in it, how do you identify it ? It is to be hoped that there will be other helpful features in the spectrum.

Concerning emission lines, there may be some galaxies with active nuclei and high excitation lines but in general there will only be the emission lines of HII regions heated by stars with black body temperatures of, say, 30 000 K. None of the strong emission lines observed in Seyfert nuclei will be observed. λ 3727 should be useful out to z $\approx$ 1. The strength of Lyman-α is unknown but may be usable. The spectra of normal galaxies measured with IUE so far do not hold out much promise but there is an urgent need for more studies with this satellite so that it is clearer what will be possible at large redshifts.

Oke: For the last few years, Jim Gunn and I have been measuring the redshifts of the brightest galaxies in clusters which were discovered by purely optical means according to strict magnitude selection criteria. About 80 brightest cluster galaxies were measured in the magnitude interval 19 to 22. About 75 of these galaxies have m < 21.5 and 90% of these have normal energy distributions. Their redshifts are typically about 0.5. About 5-10% of these 75 are peculiar in the sense that they are blue and redshifts have not be determined. Thus, there is not much evidence of colour evolution in this sample of galaxies.

We have, however, 6 objects with m $\approx$ 22. Three of these are normal galaxies like those at small redshifts but with redshifts z $\approx$ 0.55. The three others have peculiar energy distributions and the redshifts are not certain. It is expected that they should have redshifts z $\approx$ 0.6-0.65 and the red end of the spectrum would agree if they have z $\approx$ 0.65. However at shorter wavelengths, there is no H and K break and the spectrum is much bluer than that of a normal galaxy. These observations suggest that the percentage of peculiar blue objects increases at z $\approx$ 0.6.

The above observations were made with the multi-channel spectrometer. To go to fainter magnitudes, particularly in the red, Jim Gunn has built a low resolution CCD spectrometer with very high quantum efficiency in the red which should take us out to z $\approx$ 1 and m $\approx$ 23.5. For larger redshifts we will have to take UV spectra as described by Spinrad and this looks quite promising.

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Gott: Local tests for the value of Ω complement the classical cosmological tests which use objects at large redshifts. Local tests include virial mass determinations in groups and clusters of galaxies and statistical virial theorem studies. These are and will continue to be essentially ground based projects. These tests measure all the mass, visible and invisible, which clusters with the galaxies. There are some theoretical difficulties with having a large fraction of the mass of the universe in a form which does not participate in this clustering (cf. Gott, Gunn, Schramm, Tinsley 1974 Ap. J., 194, 543).

The most important local test of Ω for which the Space Telescope will be of great help is the mapping of the velocity field in the Local Supercluster. The observational prospects for such a study with ST were covered by Tammann in his talk yesterday. This type of study will provide a sensitive test for the value of Ω due to the clustered component. Counts of galaxies show the Local Supercluster to be a density enhancement of a factor of several over the mean density in the universe. In the standard picture, the Local Supercluster started as a small density enhancement at recombination which because of its excess density has accelerated more than the rest of the universe. Thus we expect the current expansion rate within the Local Supercluster to be slower than outside. The value of Hubble's constant measured within the Local Supercluster (H_{IN}) should be smaller than the value measured outside (H_{OUT}) using galaxies with $V \gtrsim 3000$ km s^{-1}. For a given local density enhancement, the ratio (H_{IN}/H_{OUT}) depends on the value of Ω. (We will assume a cosmological constant $\Lambda = 0$ throughout). The lower the value of Ω the closer the ratio (H_{IN}/H_{OUT}) is to unity. In a low density universe the overall deceleration is small and the additional deceleration produced by a density enhancement is also small.

To illustrate the sensitivity of this test for Ω let me compare as examples the values of H_{IN} , H_{OUT} reported by Tammann and Huchra yesterday.

First let me describe Tammann's results. Sandage, Tammann & Yahil (1979 private communication) have found that a sphere of radius $\sim$ 20 Mpc centered in the Virgo cluster contains approximately 4 times the number density of galaxies as a larger surrounding region. Tammann finds $H_{OUT} \simeq 55$ km s^{-1} Mpc. From distance indicators he expects the Virgo cluster to appear at redshift $V = 1100$ km s^{-1}. Its actual velocity is 950 km s^{-1} indicating that we have a peculiar infall velocity of $\sim$ 150 km s^{-1}. This gives $H_{IN} \simeq 47.5$. Combining H_{IN}, H_{OUT} and the enhancement factor of 4 we find $\Omega = 0.06$. Since H_{OUT} is a function of Ω we can also solve for the present age of the universe : $t_o = 16.5 \times 10^9$ yr. This is consistent with the age of the oldest globular cluster stars. The ages of the oldest globular cluster stars depend on the primoridal Helium abundance which depends on H_o and Ω. For the above values we find $t_g \simeq 15 \times 10^9$ yrs. (In fact Gunn (1978) has shown that with current

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data $t_g \leq t_o$ requires $H_o \lesssim 60$ km s^{-1} Mpc^{-1}). The Tammann values for H_{IN}, H_{OUT} produce a low density universe with a consistent age.

Huchra reported values of $H_{IN} \simeq 62$ km s^{-1} Mpc^{-1}, $H_{OUT} \simeq 90$ km s^{-1} Mpc^{-1}. With these distance scales Huchra places the local supercluster galaxies a factor 1.25 further away relative to the distant galaxies than Tammann. The relative number density of galaxies in the supercluster is decreased by $(1.25)^3$ but each galaxy becomes more luminous by $(1.25)^2$ so the luminosity density enhancement in the Supercluster is decreased by a factor of (1.25) to a value of 3.2 times the density outside. With this value and H_{IN}, H_{OUT} we compute $\Omega = 0.35$, and $t_o = 8.6 \times 10^9$ yrs. Note that the ratio H_{IN}, H_{OUT} gives a sensitive test of Ω. The above value of t_o is perhaps embarrasingly small. For fixed H_{IN}, increases in H_{OUT} shorten the age of the universe both because H_{OUT} is larger and because this produces an additional deceleration. One must also note the observational point that any Malmquist bias (cf. Tammann's discussion) will have the effect of increasing H_{OUT} relative to H_{IN} causing us to overestimate Ω.

With the Space Telescope one can map the velocities and distances of galaxies out to $V \gtrsim 3000$ km s^{-1}. One can measure the density enhancement due to the Local Supercluster and the Hubble expansion inside and outside the supercluster. This will give us an important independent estimate for the value of Ω which will supplement those obtained from clusters and groups of galaxies and those from classical tests with galaxies at large redshifts.

Ostriker: I want to discuss dynamical effects in the evolution of galaxies and how this can be tested by observation. There are two forms of dynamical evolution. The first is tidal stripping which must be very common in the Universe and is the process by which stars are torn from the outer parts of galaxies making them fainter. The other is merging of galaxies (or cannibalism) which is very much rarer. In general merging of galaxies is not important and it is certain that most E galaxies did not form in this way. However, for galaxies in clusters and, in particular the brightest galaxies in clusters which are important for cosmology, merging is important and I want to address the question of estimating how much merging has taken place in a given cluster.

There are three dominant effects. First, with time the galaxies get brighter and bigger, the radius being conveniently measured by the parameter $\alpha = d(\log L)/d(\log r)$. Second, the magnitude - core radius relation deviates from the relation for normal galaxies. Third, brighter galaxies are redder than fainter galaxies and therefore during cannibalism, the brighter the galaxy gets, the bluer it gets rather than redder. Thus, in all three cases, the merged galaxies deviate from the normal relation.

The problem is that the "normal" relations for these quantities are not well known, in particular, core radii are very poorly known. My proposal for ST is to measure properties such as colours, core radii etc for normal galaxies and establish the normal relations. If one then sees objects deviating from the standard relations, one can correct them back to the standard relations through the theory of merging galaxies and thus eliminate this dynamical effect when one is studying the redshift-magnitude relation.

Wilkinson: Partridge and Peebles suggested two ways of searching for primaeval galaxies. The first is the search for the background light from young galaxies if there were a burst of star formation at large redshift. The problem is that the background due to zodiacal light is very high in the waveband where it is best to search and there are only upper limits on the background. The alternative is to search for individual very red extended objects which may be identified with young galaxies. We have deep observations using CCD detectors on the 4-metre Kitt Peak telescope which we are using to search for these objects at very faint magnitudes. We have not found any of these faint red extended objects in 8 fields. Using the WFC on Space Telescope, I estimate that in a single 1-hour exposure one will gain perhaps 3 to 5 magnitudes over what can be done from the ground and this is all because of the much lower sky background at 1 μm in space.

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