47 . COSMOLOGY (COSMOLOGIE)

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1. Hubble Constant, Deceleration Parameter, and the Large-Scale Distribution of Matter in the Universe

(G.O.Abell)

A. The Hubble Constant

The precise value of the Hubble constant, H_o, is today a matter of considerable controversy. The well-known study by Sandage and Tammann is published in a series of papers in the Astrophysical Journal from 1974 to 1976. Briefly, Sandage and Tammann determine distances to nearby galaxies in which cepheid variables can be observed. In those galaxies, of presumably known distance, they measure the linear diameters of the largest HII regions (which they find to be correlated with galaxy luminosity class). Using these data as calibration,they find distances, and hence absolute magnitudes, of more distant spirals of various luminosity classes from the angular sizes of their largest HII regions, thereby providing a new calibration of the luminosity-class-absolute magnitude relation for Sc spirals. Finally, they use the new calibration to determine distances to still more remote Sc spirals of recognized luminosity class, and whose radial velocities are presumed to be great enough to be indicative of the cosmological Hubble flow. From various treatments of their data, they find values for H_o in the range 50 to 55 km $s^{-1}Mpc^{-1}$.

The steps leading to the determination of H_o have been reevaluated by de Vaucouleurs. (The first two papers in his series appear in the Astrophys. J., 223, 351 and 730, 1978). De Vaucouleurs differs with Sandage and Tammann on the calibration of primary distance indicators and on the correction for galactic absorption; he prefers a value of H_o near 80 to 85 km $s^{-1}Mpc^{-1}$ [According to G. de Vaucouleurs comunication a detailed re-examination of primary secondary and tertiary distance indicators by G. de Vaucouleurs (see Commission 28 report) and new studies of the velocity field (from spirals only) within and without the Local Supercluster (LSC) indicate that outside the LSC the unperturbed (low-density) Hubble constant is H_o = (100 ± 10) km s^{-1} Mpc^{-1} (de Vacouleurs 1978). Distances of three galaxy clusters (Virgo, For I, Hya I) - of which two are outside the LSC-derived from globular clusters in elliptical and lenticular galaxies only gave H_o = (86 ± 9) (de Vacouleurs 1977) - I.Novikov]. Kennicutt (1978) has looked carefully into the problem of defining and measuring sizes of HII regions in other galaxies, and suggests a moderate increase in H_o

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over the Sandage-Tammann value. Several additional investigators advocate values of H_0 in the range 65 to 100 km $s^{-1}Mpc^{-1}$.

Two independent determinations of H_0 that do not depend at all on primary distance indicators are worthy of mention. One is an ingenious approach by Lynden-Bell (1977), who interprets so-called hyper-light expansion velocities in radio galaxies as due to two plasma clouds ejected at relativistic velocity from an invisible collapsed object at the center of the galaxy. From VLBI observations of the separation of the sources as a function of time, he determines the angle between the motion of the clouds and the line of sight, which, with the sources assumed to be moving with the speed of light, determines the distance of the radio galaxy. From his analysis of 3C120, Lynden-Bell finds $H_0 = 110 \pm 10$ km $s^{-1}Mpc^{-1}$. The validity of the procedure is, of course, subject to the correctness of the model.

In another approach, Branch (1977) applies the Baade-Wesselink method to the analysis of the expanding photospheres of supernovae. The variation of its total light, combined with temperatures derived from its colors, gives the relative rate of increase of the size of a supernova shell. The absolute rate of increase is found from the Doppler shift of the absorption lines, and the combination determines the distance and H_0. Branch finds $H_0 = 49 \pm 9$ km $s^{-1}Mpc^{-1}$. His analysis assumesthat the effective temperature of the emitting shell is correctly given by its color, and that the absorption lines and continuous spectrum come from the same region of the expanding photosphere.

Tammann points out that a large value of H_0 makes our Galaxy anomalously large compared to distant galaxies. It should also be noted that a large value of H_0 allows only a short age for the universe: with $H_0 = 100$ km $s^{-1}Mpc^{-1}$, even the extreme open Fridmann model has an age under 10^{10} yr, less than the ages of globular clusters according to stellar evolution theory. But these are model-dependent arguments, and ought not be allowed to bias our judgment of observational analyses. The observations, however, are difficult, complex, and subject to numerous selection effects, some rather subtle. At present it is probably wise to regard H_0 as uncertain by at least a factor of 2.

B. The Deceleration Parameter

Different approaches to estimating the deceleration parameter, q_0 (or density parameter, $\Omega = 2\,q_0$), also give discordant results. Small values for q_0 (< 0.5, corresponding to open models of the universe) are suggested by: (1) The observed deuterium-hydrogen ratio in interstellar space ($D/H \sim 10^{-4}$ to 10^{-5}) favor $q_0 < 0.1$, but this assumes that the interstellar deuterium is primordial and the correctness of the standard model for the big bang. (2) If $H_0 \gtrsim 50$, $q_0 \succ 0.5$ leads to an age of the universe less than the age 13×10^9 yr that stellar evolution theory predicts for globular clusters. A value of $q_0 > 0.5$ is still possible within traditional relativistic models if H_0 50 km $s^{-1}Mpc^{-1}$, if $\Lambda > 0$, or if stellar evolution ages are far too high. (3) The fact that superclusters appear to be expanding (e.g., Rood 1976, Abell 1978), suggests that they are relatively low local density enhancements, so that the global value of q_0 should be quite low. (4) Most analyses of the relation between redshifts and angular sizes of clusters of galaxies (e.g., Bruzual and Spinrad 1978; or Hickson 1977) lead to

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small estimates of q_o (Bruzual and Spinrad find $q_o \simeq 0.25$), but with rather large uncertainty.

Large values of q_o (>0.5, corresponding to closed models) are suggested by: (1) The log z - m_{bol} relation (Hubble law) has now been determined to $z > 0.75$. To $z = 0.3$ the data are best fit with $q_o = +1.0$; more recent data, to $z = 0.4$ (kristian, Sandage, and Westphal 1978) give $q_o = 1.6 \pm 0.4$; no correction has been applied, however, for evolution of galaxian magnitude, and when evolution is allowed for, $q_o = 0$ is still possible. (2) The small-scale isotrotropy of the 3K microwave radiation places severe limits on density concentrations prior to decoupling; it is easier to understand how condensations can grow and form galaxies, clusters, and superclusters after decoupling if $q_o > 0.5$. (3) Data from Davidsen, Hartig and Fastie (1977) on the ultraviolet spectrum of 3C273, and observations of a selection of QSOs by Baldwin, Burke, Gaskell and Wampler (1978) indicate a correlation between continuum luminosity and emission-line equivalent width for these objects. Using line strengths to so estimate luminosities of high- and low-redshift QSOs, these authors find $q_o \simeq 1$ to 2. This result, however, assumes that the correlation does not depend on z (i.e., time), an assumption that is questionable, especially in light of Green and Schmidt's (1978) finding that the population of QSO's increases strongly with z.

The most reliable estimate of q_o is probably still from estimates of the mean cosmic density. Very many investigators have made estimates of this quantity; for example, Gott and Turner (1976) from analysis of nearby groups of galaxies, Turner and Ostriker (1977) from galaxies within 270 Kpc, Sargent and Turner (1977) from the dispersion in redshift in the Hubble diagram, Geller, Davis and Huchra (1978) from application of a cosmic virial theorem, and Abell (1975) from the large-scale distribution of galaxies and clusters. The values of q_o found range from 0.01 to 0.35, and most are 0.1. These estimates usually include the contribution of the kind of invisible intracluster matter that can affect the virial masses of groups and clusters. On the other hand, no single determination of q_o is definitive, and the combination of several very shaky results does not necessarily lead to a correct result. At present, the question of the openness of the universe remains open. [De Vaucouleurs and Pence (1976) re-discussed the use of the light curves of type I supernovae as cosmological clocks taking into account K-corrections and other effects. The time dilatation effect predicted by most models was detected (confirming previous conclusions of B.W.Rust), but observations of more distant supernovae will be needed for a critical test of competing models - I.Novikov .]

C. Large-Scale Distribution of Matter in the Universe

A less ambiguous picture is emerging of the large-scale distribution of galaxies and clusters. Clustering on all scales up to that of superclusters (50 to 100 Mpc for $H_o = 50$ km $s^{-1}Mpc^{-1}$) has been indicated by the statistical studies of Peebles and others over the past decade. The past three years, however have seen a rising interest in the study of individual superclusters. These have included the Local Supercluster and others superclusters in Coma, Hercules, and Perseus. Large numbers of radial velocities are now available to isolate foreground and background galaxies, and a great deal of photometry has been carried out. Investigators include de Vaucouleurs, Eastmond, Abell and Jones (Local Supercluster), Tifft, Gregory, Rood, Chincarini, and Thompson (Coma supercluster), Tarenghi, Tifft, Chincarini, Rood, and Thompson (Hercules supercluster), and Jõeveer and Einasto (Perseus supercluster). For discussion and specific references, see papers by many of these authors in IAU Symposium 79.

The evidence available suggests that all of these superclusters contain rich clusters, groups of galaxies, and probably individual galaxies, but isolated galaxies do not seem to occur between them. There is no evidence that the systems are gravitationally bound; indeed, available evidence (although meager) indicates that they are expanding with the normal Hubble flow - or at least they are expanding nearly as fast. The most remarkable thing is that all appear to be flat, suggesting the disk or "pancake" structures predicted by the theory of galaxy formation of Doroshkevich, Sunyaev, and Zel'dovich.(See IAU Symp. 63).

The hierarchy of clustering does not seem to extend beyond superclusters. Number-magnitude counts of galaxies by Rainey (1977) are incompatible with density enhancements over the mean by a factor of 2 on scales larger than 300 Mpc. The isotropy of faint radio sources (e.g., see Webster 1976) also rules out clustering on very large scales. Finally, Rainey's counts of faint galaxies and a similar investigation by Brown show there to be a very high degree of isotropy in the galaxy distribution in different directions in the sky.

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2. Radio Astronomy and Cosmology

(M.S.Longair)

Since the last survey on this topic was written for Reports on Astronomy (Longair 1976), a number of comprehensive reviews have appeared. The proceedings of two IAU symposia of direct relevance to this topic have been published, IAU Symposium N 74, "Radio Astronomy and Cosmology" (Jauncey 1977) and IAU Symposium N 79, "The Large Scale Structure of the Universe" (Longair and Einasto 1978). In addition, the long-awaited review by Scheuer (1975) has now appeared and more recently the whole subject of observational cosmology has been surveyed in the 8th Advanced Course of the Swiss Society of Astronomy and Astrophysics (Gunn, Longair and Rees 1978). The summary which follows is based upon my contribution to that volume. The accompanying reviews by Gunn and Rees are strongly recommended as a complementary view of observational cosmology from the point of view of the interrelation with optical studies and with the problems of galaxy formation.

A. THE MICROWAVE BACKGROUND RADIATION

A.1. The Spectrum of the Radiation

Since the successful pioneering balloon flights of the groups at Queen Mary College, London (Robson et al. 1974) and at the University of California at Berkeley (Woody et al. 1975), which established the convergence of the background spectrum at wave-lengths $\lambda \sim 1$ mm, there have been a number of unsuccessful flights. Most recently, the Berkeley group have succeeded in making a measurement from observations taken at about twice the altitude of their previous flight and obtained a spectrum which is essentially uncontaminated by atmosphere emission in the Wien region of the spectrum (see Boynton1978). The details of the observations have not yet been published but it is understood that they are in excellent agreement with a Planck distribution having $T_r = 2.9$ K.

A.2. Large-scale fluctuations in the background radiation

The most important recent development has been the measurement of a significant dipole term in the large scale distribution of the background radiation. The measurements of two groups (Corey and Wilkinson 1976, Smoot, Gorenstein and Muller 1977) provide consistent estimates of this dipole term which only appears at the level of about $\Delta T/T \approx 10^{-3}$. Interpreted in terms of the velocity of the observer with respect to the frame in which the background radiation is 100% isotropic, the dipole term corresponds to a velocity of about 330 km s^{-1} in the direction $\alpha \sim 11$ hr, $\delta \sim -10^{\circ}$. This velocity corresponds to the vector sum of the Sun's motion with respect to the centre of the Galaxy, the Galaxy's motion in the Local Group and the Local Group's peculiar velocity with respect to the uniform Hubble flow. If the Solar motion with respect to the Local Group is taken to be ~ 300 km s^{-1} in the direction $\ell = 90^{\circ}$, $b = 0^{\circ}$, the peculiar motion of the Local Group with respect to the frame of reference in which the microwave background radiation is isotropic is ~ 600 km s^{-1} in the direction $\alpha \sim 10^h$, $\delta \sim -28^{\circ}$; this direction lies at roughly an angle of 45° to the Virgo cluster which lies at the centre of the Local Supercluster.

This is a very tantalizing result. First of all, it is very much larger than the average deviations of groups and clusters of galaxies from the mean Hubble flow. According to Sandage and Tammann the deviations from the mean Hubble flow for the brightest galaxies in clusters are less than 250 km s^{-1} while Tammann and Kraan (1978) find that the nearby groups of galaxies (including the Local Group) have deviations less than 50 km s^{-1} from the standard Hubble flow. A possible solution is that the whole of the Local Supercluster is moving at $v \sim 600$ km s^{-1} with respect to the mean Hubble flow. If the peculiar velocity of 600 km s-1 were due to the gravitational influence of the Local Supercluster, then the latter would have to be very massive and the mean density of matter in the local volume of space would correspond to $\Omega \sim 1$. Similar conclusions can be drawn from application of various forms of the "cosmic virial theorem" which relates the mean peculiar velocity of objects in the Universe to the mean density of the Universe (see Peebles 1976, Gott 1978). On the other hand, studies of the Hubble flow within the Local Supercluster have not shown any large departures from the mean Hubble flow (Sandage, Tammann and Hardy 1972, Abell 1978), arguing against the presence of sufficient mass to cause a peculiar velocity of 600 km s^{-1}. According to Gunn (1978), perhaps the least objectionable solution is that the motion is induced by a small perturbation on very large scales which is far away. These observations obviously have very profound implications for our understanding of the large-scale structure of the Universe and it is very important that they be substantiated by further experiments, particularly those in the southern hemisphere which will provide independent evidence on the anisotropy.

Once the dipole term is removed, Smoot et al. (1977) find no evidence for a quadrupole term, their upper limit corresponding to $\Delta T/T \lesssim 3 \times 10^{-4}$.

A.3. Small scale fluctuations in the background radiation

There is still no positive detection of fluctuations in the intensity of the microwave background on small angular scales. At 1 mm, Caderni et al. (1977) have obtained an upper limit $\Delta T/T \lesssim 1.2 \times 10^{-4}$ on angular scales $\theta \sim 25$ arc min. Parijskij (1978) has reported much lower upper limits from observations made with the RATAN-600 radio telescope; they correspond to $\Delta T/T \lesssim 3 \times 10^{-5}$ and 2×10^{-5} on angular scales 10 and 100 arc min respectively at a wavelength of 4 cm. Full details of these observations have yet to be published. The problems which these upper limits pose for theories of the origin of galaxies and clusters of galaxies have been reviewed by Sunyaev (1978). It turns out that as yet there is no serious conflict between different theories and the observations but these upper limits are now coming close to the values expected from theory. In addition, at the level $\Delta T/T \sim 10^{-5}$, a number of other astrophysical phenomena may give rise to fluctuations - discrete radio sources with flat radio spectra, fluctuations associated with the process of reheating the intergalactic gas, fluctuations in the optical depth of the Universe to Thomson scattering. Thus, even if fluctuations in the microwave background are discovered at the level $\Delta T/T \sim 10^{-5}$, it may not be easy to disentangle these competing effects.

The one class of small scale fluctuation which now seems esta-

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blished is that associated with Compton scattering by hot gas in clusters of galaxies (Sunyaev and Zeldovich 1970). The early observations by Gull and Northover (1976) and by Lake and Partridge (1977) have been the subject of some dispute but more recently the effect has been well established in Abell 2218 and the shape of the depression measured (Birkinshaw, Gull and Northover 1978). In two other clusters it has been possible to measure the angular size of the depression and from these three observations Birkinshaw (1978) has applied the method proposed by Gunn (1978) to estimate the Hubble constant by combining his results with those on the X-ray emission and velocity dispersions of the clusters. The results have large errors as yet but favour low values of the Hubble constant.

A.4. Prospects

The most exciting prospect in this field is the NASA Cosmic Background Explorer (COBE) which, it is intended, will measure the spectrum of the microwave background radiation very precisely at wavelengths at and beyond the maximum of the Planck spectrum. Very small deviations from a Planck spectrum $\Delta I_\nu / I_\nu \approx 10^{-3}$ will be detectable. In addition, the isotropy of the background on scales $\theta \gtrsim 7^o$ will be measured with very high precision $\Delta I/I \sim 10^{-5}$. The other field of most significance is the continued search for fluctuations on angular scales $1 \lesssim \theta \lesssim 60$ arc min to a comparable sensitivity level.

B. EXTRAGALACTIC RADIO SOURCES

B.1. Surveys of Sources and the Isotropy of their Distribution

Details of many of the surveys described at IAU Symposium No. 74 "Radio Astronomy and Cosmology" have now been published. The most striking feature of these surveys remains the remarkable uniformity of the radio source population. At all frequencies from 178 MHz to 2.7 GHz at which large surveys have been completed, power-spectrum analyses of the surface distribution of radio sources by Webster (1977) have revealed no evidence that radio sources are distributed other than at random on the sky. A weak clustering effect has been detected by Seldner and Peebles (1978) among 4C radio sources on the scale of a few degrees at about the level of the upper limit to the fluctuations claimed by Webster.

To convert these isotropy limits into limits to the spatial density variation of radio sources requires an estimate of their typical redshift. Probably most sources in a catalogue such as the B2 survey are at distances corresponding to $z \sim 1$-3. Then, from the Bologna survey, which contains about 9000 sources (Fanti, Lari and Olori 1978), Webster quotes a limit to the amplitude of large scale fluctuations $\Delta N/N < 3\%$ on a scale of 1 Gpc^3, i.e. if one moves a cube of side 1 Gpc around the Universe, the fluctuations in the total numbers of sources counted from one place to the other is less than 3%.

A number of comments should be made about these results. First, the limits to the isotropy only increase as $N^{-1/2}$ and hence it will be very difficult to improve on the present limits by a substantial factor in the foreseeable future. Second, these limits refer to physical scales much larger than those studied at optical

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wavelengths through the covariance function for galaxies. Third, when radio source surveys reach the level 0.1 - 1 mJy, it should become possible to observe the clustering of radio sources associated with clusters of galaxies at redshifts $Z \sim 1$ to 2. This is because at these flux densities, the surface density of sources becomes comparable to that of clusters at these redshifts and since a significant fraction of sources of these luminosities lie in rich clusters, there should be a significant effect associated with the second order clustering of clusters.

B.2. Source Counts

The outcome of IAU Symposium No. 74 "Radio Astronomy and Cosmology" was that there is good agreement among observers about the source counts at different frequencies. There seemed to be no anisotropics or anomalies which could not be ascribed to statistical fluctuations. The most remarkable result is that whereas the source counts at low frequencies, $\nu < 1.4$GHz, exhibit a strong convergence at low flux densities in the sense $dN \propto S^{-\beta}\, dS$ with $\beta < 2$, at higher frequencies especially at 5GHz the source counts remain remarkably flat to the lowest flux densities studied (Figure 1 - from Wall 1977). Much of the evidence for this flattening comes

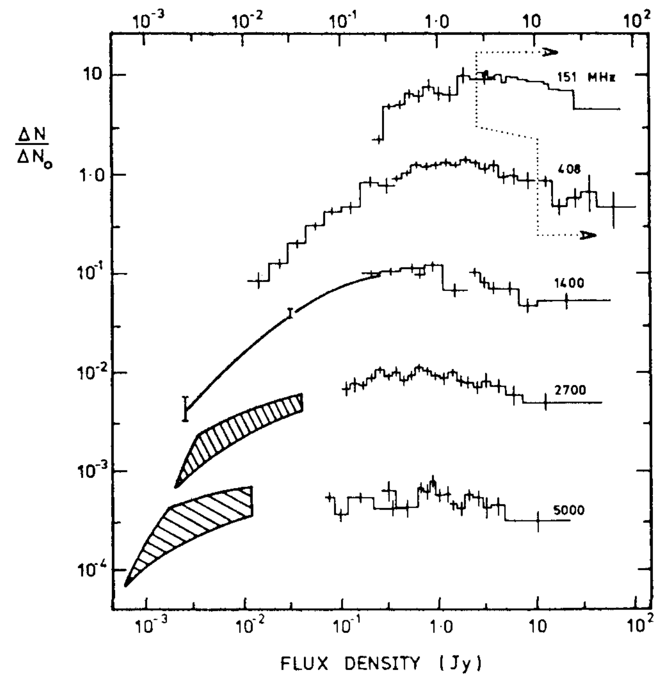

Figure 1. The differential counts of radio sources at frequencies 151,408,1400,2700 and 5000 Mhz (Wall 1978). The differential count ΔN has been normalized arbitrarily to the local Euclidean prediction $\Delta N_0 \propto S^{-5/2}\Delta S$. The shaded areas represent estimates of the $\Delta N(S)/\Delta N_0$ relations from analysis of background fluctuations. For detailed references to the sources of the observations, see Wall (1977).

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from "confusion" surveys which provide only statistical information on the counts without identifying individual sources. The inference is that there must be a new population of sources which appears only at low flux densities at high frequencies. Because the flat source count extends to low flux densities, these must be relatively low luminosity sources with flat spectra, possibly similar to the compact cores found in some elliptical galaxies.

B.3. Optical identification programmes

The problem in interpreting the anomalies in the source counts has always been that most of the radio sources studied are so distant that they cannot be identified optically. There have been a number of recent optical identification surveys which have improved the situation somewhat. At high flux densities, $S_{178} > 10$ Jy, the optical identifications are now over 90% complete to a limiting magnitude $m_{pg} \approx 22.5$ (Laing et al. 1978). Most of the faint identifications $m_{pg} \gtrsim 20$ are distant radio galaxies and probably the unidentified sources are of the same nature. At high frequencies, $\nu > 1$GHz a similar success rate is found, the main difference being the much larger fraction of sources with flat radio spectra, $\alpha \approx 0$, most of which are associated with quasars. At intermediate flux densities $S_{408} \sim 1$ Jy, Grueff and Vigotti (1977) have achieved over 63% completeness using deep 48-inch Schmidt plates. At the lowest flux densities, $3 < S_{1400} < 500$ mJy, de Ruiter et al. (1977) found only 25% identifications using deep 48-inch Schmidt plates but achieved 47% when deep 4-m plates were used. A similar result has been found by Perryman (1979) who has looked for deep identifications in the 5C6 and 7 surveys. At 1.4GHz, the same frequency as de Ruiter et al., about 45% completeness was found but at 408 MHz, only about 20-25% was obtained.

These results which are crucial for interpreting the radio source counts indicate that progress has been made but that it will be a long and arduous task to obtain significantly improved figures. With the development of CCD detectors, it will become practicable to study the unidentified fields to very much fainter magnitudes and eventually it will be possible to use the NASA Space Telescope to attain the faintest magnitudes.

B.4. Source Counts and V/V_{max} tests for quasars

Complete samples of quasars selected at both low and high frequencies have become available recently (for review see Schmidt 1978). These results may be summarized as follows. For samples of sources with steep radio spectra, $\alpha \sim 0.75$, the mean value of V/V_{max} is consistently found to be 0.67 as opposed to the value 0.5 expected for a uniform distribution of sources. For sources with flat radio spectra, significantly smaller values are found. A compromise value consistent with all the data on the latter sources is $\langle V/V_{max} \rangle \approx 0.58 - 0.60$ which is still somewhat larger than the value expected for a uniform distribution. This result is consistent with the counts of sources with flat spectra selected at high frequencies.

Interpreted literally, these results suggest that the evolutionary changes in the comoving space density of flat spectrum sources are significantly smaller that those of sources with steep spectra. If the evolution is described by an exponential evolution function with cosmic epoch $f(t) = \exp(\beta(t_o-t)/t_o)$ where t_o is the present epoch, $\beta = 10\pm2$ for steep spectrum radio sources whereas $\beta \sim 3$-4 for flat spectrum sources, in both cases assuming $\Omega = 0$.

Green and Schmidt (1978) have completed a systematic search for bright radio-quiet quasars having $B < 15.7$. In 1434 square degrees of sky, they found only 4 quasars. Combining this result with deeper searches for radio quiet quasars by Bracessi and by Sandage and Usher, they find an integral source count $N(\geq S) \propto S^{-\beta}$ with $\beta \approx 2.3$-2.4. The exponent is much greater than the Euclidean value $\beta = 1.5$ in the same sense as the counts of radio sources at high flux densities. This result indicates that radio quiet quasars also exhibit strong cosmological evolution.

B.5. Interpretation of radio source counts

It is become possible to construct more detailed models for the evolution of the radio source population as the counts are defined with much greater precision and the optical identifications continue to increase. These new data make it more difficult to construct simple models for the evolution of the source population, some examples of the necessary level of complexity being illustrated by the models of Wall, Pearson and Longair (1977). To account for the distributions at other wavelengths, a number of complicating factors will have to be included:
(a) the new population of faint, flat-spectrum sources at high frequencies,
(b) the correlation between radio luminosity and spectral index for radio galaxies and possibly quasars,
(c) the different evolutionary behavior of quasars with steep and flat radio spectra. As yet no models have been constructed which can accommodate all the observations but the way in which one would go about the task is clear. A further complication is the way in which these models are related to the distribution of radio quiet quasars. The whole subject is plagued by an inadequate understanding of the astrophysics of individual radio sources and of why it is that particular objects become strong radio sources.

B.6. Angular diameter - redshift tests

Miley's original (1971) analysis of the angular-diameter redshift (θ-z) test has been extended to fainter samples of quasars by Hooley, Longair and Riley (1978) and by Wardle and Potasch (1977). If radio galaxies and quasars are all considered together, the θ-z relation does not show a marked minimum at redshifts $z \sim 1$ as expected in all high density world models. The results are at best marginally consistent with $\Omega = 0$ and can be described by the relation $\theta \propto z^{-1}$. If quasars alone are considered, the effect is much less marked and it is difficult to disentangle effects associated with luminosity from those associated with redshift because most of the quasar samples are drawn from flux density limited samples. The analyses of Hooley et al. and Wardle and Potasch suggest that much of the observed flattening of the θ-z relation may be due to an anti-correlation of physical size with radio luminosity but the statistics are still inadequate to make any strong statement.

That there should be physical changes in the sizes of extended radio sources with cosmological epoch was suggested by the work of Swarup and Kapahi (1975) on the angular diameter-flux density re-

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lation. The flattening of this relation at low flux densities has been confirmed by more extensive surveys described by Ekers and Miley (1977). These results would be consistent with physical size evolution $d \propto (1+z)^{-\gamma}$, $\gamma \approx 1-1.5$ for extended radio sources.

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3. Space Astronomy and Cosmology

(S.Hayakawa)

In spite of rapid progress in space astronomy, a majority of papers on cosmology published in the past three years are not directly concerned with space observation. In the Astrophysical Journal, for example, about 110 papers are indexed under cosmology in 1975- 1977, and only a little more than ten papers deal with space observations. Adding several papers relevant to cosmology but not indexed under cosmology, the number of space cosmology papers does not exceed twenty. However, a number of results obtained by space observation are of primary importance in cosmology.

The results to be reported here are obtained in the millimeter, X-ray and γ-ray ranges. Observations in the millimeter range is reported in the section "Radio Astronomy and cosmology" of this report; observations of infrared and ultraviolet radiation do not yet give information of direct relevance to cosmology.

A. EXTRAGALACTIC X-RAY SOURCES

Extragalactic X-ray sources provide candles for cosmological study because of their high luminosities and a high signal to noise ratio in X-ray detection. Since most X-ray sources thus far found are nearer than $z = 0.1$ except for a few quasars, they are by themselves little relevant to cosmology. In the very near future, however, X-ray sources will give important information on cosmology owing to deep sky surveys with an orbiting X-ray telescope.

Extragalactic X-ray sources are divided roughly into two categories. One consists of compact sources which are mostly Seyferts and emission line galaxies, while the other of clusters of galaxies.

The compact sources are characterized by power law spectra with low energy cut-off and rapid time variations. X-ray are probably emitted from a compact core of size as small as or smaller than 10^{15} cm. The synchrotron self-Compton process, Compton scattering of radio photons by those electrons which emit radio waves by synchrotron radiation, may be responsible for X-ray emission from Seyferts. The X-ray luminosity in the range 2-6 keV distributes over $3 \times 10^{42} - 1 \times 10^{45}$ erg s^{-1} and the space density is of the order of 10^{-7} sources per Mpc^3 for $H_0 = 50$ km s^{-1} Mpc^{-1}.

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by a superposititpn of known extragalactic sources. In the energy range 2-6 keV, Schwartz estimates that clusters of galaxies and Seyfert galaxies contribute to 35% and 22%, respectively, of the total intensity for zero deceleration parameter and without the evolutionary effect. If their contributions are subtracted, the spectrum below 20 keV is flat. It does not seem easy to explain the flat spectrum below 20 keV and the steep spectrum above 50 MeV.

It might be considered that a substantial fraction of the diffuse component could be explained by sources of high X-ray luminosities as mentioned above. However, the smallness of space fluctuations requires the volume density of such sources should be higher than 10^{-3} Mpc^{-3}. Neither emission line galaxies nor quasars satisfy this restriction.

One would therefore have to invoke speculative hypotheses, such as strong evolutionary effects so that a majority of the diffuse component is attributed to highly redshifted sources of high X-ray luminosities and a high volume density and/or the emission from intergalactic matter of a high temperature and a density comparable to the critical value; in the latter case the contribution of known sources would have to be smaller than that estimated above, so that the spectrum after subtraction of the source contribution would not be flat below 20 keV.

The present report on X-rays and γ-rays is based mainly on papers presented at COSPAR/IAU Symposium on X-ray Astronomy and at Working Group Meeting of COSPAR on 31 may-3 June and 6 June, respectively, in 1978. Since references will be found in the Proceedings, we do not give individual references, except review papers given by K.A.Pounds, M.J.Rees, S.D.Shulman, D.A,Schwartz, K.Pinkau and L.E.Peterson.

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4. Formation of Galaxies

(A.G.Doroshkevich)

For the recent three years (1976 to 1978) the essential progress was achilved as in observations as in the theory of the formation and evolution of the structure of the Universe, clusters and superclusters of galaxies. These problems were discussed in detail at the IAU Symposium No. 79 "The Large-Scale structure of the Universe", 12-16 September, 1977, Tallin, Estonia, USSR.

Among the experimental results the following are the most interesting: 1) New measurements of small-scale fluctuations of the background radiation (Parijsky et al., 1977; Parijsky, 1978), give the very low estimates for the permissible amplitude of fluctuations ($\Delta T/T < 10^{-4}$ in scales of $\Theta > 5'$). The comparison of these data with the theoretical calculations (Bonometto, Luccin, 1977; Lentsova, Chermin, 1977; Kurskov, Ozernoy, 1978; Sunyaev, 1977, Doroshkevich, Zeldovich, Sunyaev, 1978) allows the valid information

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to be obtained about the early pregalactic stages of the evolution of the Universe; and it restricts essentially the domain of permissible parameters of some theoretical models for the Universe' structure formation.

2) The available data of measurements of red-shifts of galaxies allowed to determine of the three-dimensional structure of some clusters and superclusters of Galaxies Joeveer, Einasto (1978); Tifft, Gregory (1978); Schipper, Kung (1978); Thompson, Gregory (1978); Gregory, Thompson (1978). In so doing, the cell structure was clearly revealed for the distribution of the observed matter; the galaxies is mostly concentrated in the vicinity of the boundaries of the cells in the inner region of which there are practically no galaxies. The scales $L \simeq 50$ to 100 Mpc are typical of the cells whereas the thickness of dense superclusters located at the cell boundaries is of an order of 5 to 10 Mpc. The cell structure is visually seen also at the picture of the distribution of galaxies in Lick catalogue (Seldner et al., 1977).

There are the systematical distinctions of the properties of the population of galaxies including in the rich clusters, superclusters and in the groups and clusters spare located in inner region cell (Gregory, Thompson, 1978). However there has been no yet certain statistical estimate of the effect.

These results are in good agreement with the conclusions of the adiabatic theory of the galaxy formation.

3) Numerical calculations of the correlation (covariance) functions carried out under the guidance of Prof.Peebles (Groth, Peebles (1977), Davis, Groth, Peebles (1977), Seldner, Peebles (1977), Fry, Peebles (1978), Peebles (1978) using the materials of catalogues of Zwicky, Able, Lick and Jagelonski made it possible to final typical scales $L \simeq 10\ h^{-1}$ (h is Hubble constant expressed in 100 km/sec/Mpc) and interesting empiric relations between two, three and four point correlation functions. The authors believe that these data speak in favour of an unique gravitational mechanism of clustering galaxies and clusters of galaxies and of the entropy theory of the galaxy formation, In the papers of McClelland, Silk (1977), Fall, Tremaine (1977) these problems are discussed also. The review of the state of this problem has been done by Fall (1978).

However these conclusions are not accepted. Shanks (1978) has noted that the calculations of multipoint correlation functions do not make it possible to have the rather full information about the structure the catalogue. He has suggested other methods of investigation providing more detailed information on the distribution of the investigated objects. The author believes that the structure of the Universe can be determined not only by the gravitational clustering and concludes that the adiabatic theory of the galaxy formation is in better agreement with the statistical analyses of the Lick catalogues than the entropy theory.

There was continued the development of vortex, entropy and adiabatic theories of formation of galaxies.

The above mentioned calculations of the temperature fluctuations of the background radiation is one of most important directions of the development of the vortex theory. The second direction is the investigation of the possibility of the erly formation of galaxies (see Ozernoy and Chernomordik, 1976, 1978). The detailed review of the vortex theory see Jones (1976) and Ozernoy (1978).

The considerable progress has been achived in the entropy theory of the formation of galaxies according to which clouds of

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the scale of globular clusters originated first Dicke, Peebles (1968) and then successively clustered into conglomerates with greater and greater mass. Besides the calculations of the background radiation fluctuations in this theory the numerical models of the process of clustering of gravitationally interacting point masses were developed (Aarseth, Gott, Turner, 1978; Aarset, 1978; Jones, Rees, 1978, Fall, 1978). The comparison of the calculated models with the observations was made using the methods of the statistical analysis, see also Shanks (1978). The original model of successive formation of several generations of stars and their clustering into the conglomerate of various scales was suggested (Rees, 1977; Jones, 1979; White, Rees, 1978). Rees (1978) discussed the possible origin of the background radiation on the redshift.

The development of the adiabatic theory of the formation of galaxies has being actively continued. According to this theory the objects of the scale of clusters and superclusters of galaxies originated first of all and desintegrate into galaxies, globular clusters and stars during formation. The review of the present state of this theory based on the non-linear theory of gravitational instability was made by Zeldovich (1978) and Doroshkevich, Saar, Shandarin (1978a). This theory offers the natural explanation not only for the cell structure of the Universe but also for the specific flattened form of superclusters, the peculiarities of spatial distribution of elliptical and spiral galaxies, the connection between the moment and the mass of galaxies. It is possible to calculate the function of the mass of galaxies and the clusters of galaxy (Doroshkevich, Shandarin, 1976, 1977 a,b,c, 1978 a,b; Doroshkevich, Saar, Shandarin, 1978 b).

The analysis of non-linear processes of the development of non-uniformity and the approximate non-linear theory of gravitational instability was made in papers of Doroshkevich, Kotok, et al. (1978 a,b).

The other approach to the adiabatic theory of the formation of galaxies was developed in the paper of Rees, Ostriker (1977), in which the main attention was paid to the stages of the evolution of protogalaxies and protoclusters in the gas-dynamic regime, to cooling and fragmentation of gas clouds up to the star formation.

The problems of structure and evolution of young galaxies and the problems of their observation also are closely associated with the problems of formation of galaxies.

These problems were considered in the papers of Tinsley (1978), Sunyaev, Tinsley, Meier (1978), Longair, Sunyaev (1977).

The considerable progress was also achieved in the numerical modeling of early stages of evolution of galaxies and clusters of galaxies as the system of gravitationally interacting point masses. It is the cycle of papers of Gott and Turner, and also the papers of White (1976). The review of these papers was made by Gott (1977). The papers of Binney (1976) and Aarseth, Binney (1978), should be especially noted in which the non-sphericity of elliptical galaxies is associated not with the rotation but with the anisotropy of kinetic temperature of stars emerging because of the anisotropic collapse.

Gunn (1977) and Silk (1978) also considered these aspects of the problems of formation and evolution of galaxies and clusters of galaxies.

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5. Physics Near the Cosmological Singularity

(I.D.Novikov, A.A.Starobinsky, Ya.B.Zeldovich)

During 1976-1978 the investigation of particle creation and vacuum polarization in strong gravitational fields near the cosmological singularity was continued. The structure of the renormalized energy-momentum tensor in an arbitrary curved space-time and, in particular, in the Friedmann-Robertson-Walker metric was investigated by different methods and for various types of quantum fields (e.g. Christensen S.M., 1976; Mamayev S.G. et al., 1976; Davies P.C.W. et al., 1977; Mamayev S.G.. et al., 1977; Mamayev S.G., Mostepanenko V.M., 1978). Different renormalization schemes gave the same result for the value of the renormalized energy-momentum tensor in the Friedman metric, so at the present stage the situation in this field can be considered as satisfactory. A number of elegant expressions for the amount of created particles and the rate of particle creation were obtained by Woodbouse N.M.J.(1976) in the adiabatic case when the rate is exponentially small and by Ya.B.Zeldovich A.A.Starobinsky (1977) in the opposite case. These expressions confirm the previous results by Zeldovich and Starobinsky about the rate of particle production near the anisotropic cosmological singukarity, which in turn led to the conclusion about rapid isotropisation of the cosmological expansion soon after $t = t_{pl}$.

The process of graviton production in the Friedmann-Robertson-Walker metric received wider attention. This process results in the formation of the relic background gravitational radiation with the

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nonthermal spectrum in general, its energy density being of the order of the energy density of the electromagnetic relic background. The opportunities for the detection of the gravitational background (of any origin) were investigated by L.P.Grishchuk (1976). The observational determination of the spectrum of relic gravitons with wavelengths $\lambda < 0.1$ cm, though extremely difficult, would be of utmost importance. It was shown by A.A,Starobinsky (1976) how this spectrum may be used to obtain some knowledge about the pre-singular ($t < 0$) state of the Universe (was it contraction or something else). Calculations of the graviton creation in more standard isotropic models of the Universe (with the singularity at $t = 0$) were performed by J.B.Hartle (1977) and L.P.Grishchuk (1977). Typically, the effective temperature of the gravitational background at long wavelengths significantly exceed 3°K, due to the nonthermal character of its spectrum. The exact value of this temperature and its dependence upon the wavelength crusially depends on the history of early Universe after and before $t = t_{pl}$. The back reaction of created gravitons on the evolution of the Friedmann model (also with the singularity) was calculated by B.L.Hu and L.Parker (1977).

Some cosmological consequences of the phase transitions in gauge theories see in the revue A.D.Linde (1978).

During last three years the possibility of the primordial black holes (PBH) existence (Zeldovich Ya.B., Novikov I.D, 1966; Hawking S.W., 1971) was investigated, PBH have become a subject of great interest for cosmology after the quantum evaporation of low mass black holes was discovered by S.W.Hawking (1974). The modern revue on PBH see in Novikov I.D. et al. (1978).

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6. Unconventional cosmological models

A lot of papers on the "notstandart" cosmology were published in GRG Journal, Astronomy and Astrophysics and others. There are not

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nonthermal spectrum in general, its energy density being of the order of the energy density of the electromagnetic relic background. The opportunities for the detection of the gravitational background (of any origin) were investigated by L.P.Grishchuk (1976). The observational determination of the spectrum of relic gravitons with wavelengths $\lambda < 0.1$ cm, though extremely difficult, would be of utmost importance. It was shown by A.A,Starobinsky (1976) how this spectrum may be used to obtain some knowledge about the pre-singular ($t < 0$) state of the Universe (was it contraction or something else). Calculations of the graviton creation in more standard isotropic models of the Universe (with the singularity at $t = 0$) were performed by J.B.Hartle (1977) and L.P.Grishchuk (1977). Typically, the effective temperature of the gravitational background at long wavelengths significantly exceed 3°K, due to the nonthermal character of its spectrum. The exact value of this temperature and its dependence upon the wavelength crusially depends on the history of early Universe after and before $t = t_{pl}$. The back reaction of created gravitons on the evolution of the Friedmann model (also with the singularity) was calculated by B.L.Hu and L.Parker (1977).

Some cosmological consequences of the phase transitions in gauge theories see in the revue A.D.Linde (1978).

During last three years the possibility of the primordial black holes (PBH) existence (Zeldovich Ya.B., Novikov I.D, 1966; Hawking S.W., 1971) was investigated, PBH have become a subject of great interest for cosmology after the quantum evaporation of low mass black holes was discovered by S.W.Hawking (1974). The modern revue on PBH see in Novikov I.D. et al. (1978).

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definite evidences that any of these theories has a decided superi-crity. The review of the general directions of these investigations see Ne'eman, transactions of the IAU, volume XVIA, page 151. Here we mentione few papers only: B., 1977, Acta Cosmologica, Z6, 31; Ktygier B., Krempec J., 1977, Astron. Astrophys., 61, 539; Maeder A., 1978, Astron. Astrophys. 65, 337; Magnenat P., Martine L., Maeder A., 1978, Astron. Astrophys. 67, 51.

I.D.NOVIKOV

President of the Commission

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