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INTRODUCTION
(Katsuhiko Sato)

The last three years have been very fruitful ones in cosmology research. Brilliant achievement on the spectrum and homogeneities of cosmic microwave background radiation by COBE satellite is an example. It is, however, obviously impossible to review achievements in all fields in the number of pages allocated to our commission. This report, as in past reports, consists of some details of only some selected topics. I invited six active colleagues to collaborate in the preparation of this report. The topics are 1) Large Scale Structure and Motion (A. Dekel), 2) Formation of Galaxies and Large Scale Structure (S. Shandarin), 3) Active Galactic Nuclei in Cosmology (P.A. Shaver), 4) Cosmic Microwave Background Radiation (R. B. Partridge), 5) Primordial Nucleosynthesis (H. Reeves) and 6)The Cosmological Parameters (V. Trimble). Unfortunately, review on Early Universe could not be included because of the limit of page number, though it was planned originally. Recent developments in this area would be seen in the proceedings of recent international conferences (for example, Nobel Symposium 79 on "The Birth and Early Evolution of Our Universe" Graeftavallen, Sweden, June, 1990, ed. B.-S. Skagerstam, World Scientific)

In the triennium (mid 1987 - mid 1990), commission 47 acted as a sponsor of the Symposium 139, "Galactic and Extragalactic Background Radiation", Heidelberg, June 12 - 16, 1989.

LARGE-SCALE STRUCTURE AND MOTIONS IN THE UNIVERSE
(Avishai Dekel)

The research in this field has been predominantly phenomenological and led by observations. The goal is to confront the observations with the competing theories, whose basic components are as follows: *(a)* The cosmological model, including the assumption of homogeneity and the values of Ω and Λ. *(b)* The origin of the initial density fluctuations, for example from quantum fluctuations during Inflation (review: Efstathiou 1990), from topological defects (e.g. strings, review: Bertschinger 1989), or from late explosions (review: Ostriker 1988). Of particular interest are the initial power-spectrum and the statistical nature of the fluctuations, e.g. being Gaussian or non-Gaussian (review: Kofman *et al.* 1990). *(c)* The nature of the dark matter which filtered the fluctuations before they grew to the present large-scale structure; the dark matter could be baryonic or non-baryonic, 'cold' or ' hot', depending on when it became non-relativistic (review: Primack *et al.* 1988). *(d)* Galaxy formation and the resulting relationship between the distribution of galaxies of different types and the underlying mass-density field, sometimes parametrized by the proportionality "biasing" factor b (review: Dekel and Rees 1987).

The current 'standard reference' model is a Robertson-Walker cosmology with an inflationary phase, $\Lambda = 0$ and $\Omega = 1$, Gaussian initial fluctuations that have grown by gravitational instability, $\sim 90\%$ cold dark matter (CDM) plus $\sim 10\%$ baryons, and linear biasing with $b \sim 2$. In order to allow a comparison of theory and observations on a common ground, progress is being made in parallel in developing methods for the analysis of the data, in quantifying the predictions of the competing theories, and in using appropriate statistics for the comparison. Selected observational developments are listed below, from small to large scales, and their analysis and theoretical implications are briefly discussed.

Large-Scale Kinematics and Dynamics

The development of techniques for measuring redshift-independent distances to galaxies with $\lesssim 20\%$ errors led to the current production of extended samples of galaxies with peculiar velocities, which are obtained by subtracting the Hubble velocity at the measured distance from the total velocity given by the redshift. The current samples contain about 1000 galaxies (review: Burstein 1990) whose distances were measured using

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either the luminosity-line width relation ("Tully-Fisher") or the diameter-velocity dispersion relation These measurements practically opened a new field of research – that of large-scale dynamics – where the mass-density field and the initial conditions can be recovered directly from the observed velocities of the test objects independently of the question of biasing in galaxy formation (review: Bertschinger 1990).

New methods have been developed for recovering the smoothed three-dimensional velocity and density fields from the noisy and sparse observed radial velocities and for estimating the errors in the results. One is based on potential analysis, appealing to the no-vorticity nature of gravitational flows ("Potent" by Dekel *et al.* 1990; Bertschinger *et al.* 1990). Another is searching for the maximum-probability density field given the data and the errors (Stebbins and Kaiser 1990).

The striking feature of the velocity field is a bulk flow relative to the cosmic microwave background frame, shared by the Local Group. The current Potent determination for the bulk velocity inside a sphere of radius 40 h^{-1}Mpc is 388 ± 67 $km\ s^{-1}$, compared with an rms velocity of 287 b^{-1} $km\ s^{-1}$ predicted for CDM. A better fit to the data is provided by a spherical infall model into a "Great Attractor" centered at a distance $40 - 50$ h^{-1}Mpc behind the Hydra and Centaurus clusters, with some evidence for infall from the far side as well (Dressler and Faber 1990). Gaussian smoothed at 12 h^{-1}Mpc, the peak density contrast is 1.2 ± 0.4 and the density at the Local Group is near the universal average. Also recovered are large regions of below-average densities, and signs for another large density peak in the vicsinity of the Pisces supercluster, limited by the poor sampling in that region.

Several other statistics have been applied to the present data, with only tentative conclusions so far. For example, the velocity correlation function of elliptical galaxies shows a coherence length of ~ 20 h^{-1}Mpc, higher then expected in CDM (Gorski *et al.* 1989; Groth *et al.* 1989). The cosmic "Mach number", i.e. the ratio of bulk flow to the dispersion about it, which measures the ratio of large- to small-scale power independent of biasing, has been argued to be in conflict with CDM (Ostriker and Suto 1990), but a factor of two uncertainty in the estimated values used can reverse this conclusion. Model-independent predictions have been made concerning anisotropies expected in the microwave background radiation on scales $\sim 1°$ based on the observed velocities (Bertschinger, Gorski and Dekel 1990); the Great Attractor corresponds to $\delta T/T \gtrsim 2 \times 10^{-5}$.

The current efforts focus on producing bigger and denser samples, gaining confidence in the distance measurements and improving them, estimating the errors and trying to 'beat' them with improved reconstruction methods, comparing the mass and light distributions and pursuing a quantitative comparison with theory.

Dynamics from Uniform Redshift Surveys

Uniformly-selected whole-sky samples of galaxies can be most valuable for dynamical studies; a smooth galaxy density field can be obtained and the peculiar velocity field can be extracted under the assumption that light traces mass. The distinctive development in this field is the IRAS redshift survey (with about 2000 galaxies complete to 60μ flux limit over ~90% of the sky; Strauss *et al.* 1990) and its dynamical analysis (Yahil *et al.* 1990), which provided the distribution of late-type galaxies and their estimated velocities out to ~ 100 h^{-1}Mpc. A comparison of the IRAS fields and the Potent fields in regions where both data sets are reliable yields an encouraging general agreement with a proportionality factor in the range $0.75 \leq \Omega^{0.6}/b \leq 1.15$ (e.g. Yahil 1990). The question of how to determine separately Ω and b is open; it cannot be solved in the linear regime.

A promising effort is made (Lynden-Bell 1988) to translate the large, but incomplete redshift catalog ("z-cat", compiled by J. Huchra at the CfA) into a uniform 3D optical-light map using weighting based on whole-sky complete catalogs (such as UGC and ESO).

Galaxy-Galaxy Correlations

A most remarkable development is the automatic APM survey (Maddox *et al.* 1990), which covers more then one steradian of the southern sky to $b_J = 20.5$, containing about two million galaxies to a depth of ~ 600 h^{-1}Mpc. This survey allows a reliable estimate of the angular galaxy-galaxy correlation function up to separations corresponding to ~ 30 h^{-1}Mpc. It shows more power on these scales than previously seen in the Shane-Wirtanen Lick counts (Groth and Peebles 1977), with an indication for a drop off starting only beyond 20 h^{-1}Mpc and going negative beyond 50 h^{-1}Mpc. This result is in conflict with CDM theory, which predicts no correlations beyond ~ 20 h^{-1}Mpc (e.g. Bond and Efstathiou 1984). The major source of uncertainty here is the calibration procedure.

A redshift survey of 1 in 6 random galaxies from IRAS indicates an excess of power on even larger scales (Efstathiou *et al.* 1990). A count in cells of 40 h^{-1}Mpc yields a variance of $\sigma^2 = 0.21^{+0.11}_{-0.07}$ in conflict with the value $\sigma^2 = 0.07$ predicted by CDM.

Slice Redshift Surveys – Great Walls

The efforts to explore the distribution of galaxies beyond the original CfA survey have continued through redshift surveys to J magnitude 15.5 in $\sim 90° \times 6°$ slices (Geller and Huchra 1989). The slices continue to reveal voids and sharp-edged filamentary features on scales of tens of megaparsecs within our ~ 150 h^{-1}Mpc neighbood. But the exciting new feature is the "Great Wall", extending across the sky through Coma at a distance of $\sim 80\ h^{-1}$Mpc, and its southern counterpart at a similar distance; they are coherent superstructures over 100 h^{-1}Mpc long and only $\sim 10\ h^{-1}$Mpc thick. CDM simulations predict filamentary structure in the mass distribution on scales of a few tens of megaparsecs only, but when galaxies are defined in the simulations and convolved with the observer radial selection function that has a broad peak near 80 h^{-1}Mpc, it has been shown that these filaments can join to coherent structures as observed (Park 1990).

Superclustering of Clusters

The large correlation length of rich clusters of galaxies, $\simeq 25\ h^{-1}$Mpc (review: Bahcall 1988), has been regarded as evidence for large-scale power beyond the predictions of all the Gaussian models with $\Omega = 1$ (Barnes *et al.* 1985). The non-Gaussian scenario of Cosmic Strings seemed for a while capable of producing appropriate phase-correlations among the clusters, but detailed simulations revealed high velocities that smear the cluster correlations away (Bennet and Bouchet 1990). The superclustering in the explosion scenario was shown to be appropriate provided that the dominant shells are at least $\sim 20\ h^{-1}$Mpc in radius (Weinberg *et al.* 1990), which is somewhat hard to explain physically. On the other hand, it has been realized that the indicated excess correlation of clusters may be largely due to mutual projection effects in the Abell catalog (Sutherland 1988; Dekel *et al.* 1989; Olivier *et al.* 1990), thus weakening the disagreement with CDM.

Nevertheless, there are indications that the distribution of clusters is inhomogeneous even on scales $>$ 100 h^{-1}Mpc. For example, Scaramella *et al.* (1989) have rediscovered (after Shapley) a large concentration of clusters at a distance of about 140 h^{-1}Mpc, behind the Great Attractor. This "Attratore di Tutti Attratori" also stands out in a sample of X-ray clusters (Lahav *et al.* 1989). According to a compilation of rich clusters by Tully (1987), the Shapley supercluster, as well as the Great Attractor, the Perseus-Pisces supercluster, the Coma Supercluster and the Local Supercluster, all lie in a super-duper planar structure of $\sim 600\ h^{-1}$Mpc in extent. If the mass distribution follows this very-large-scale inhomogineities, the dynamical consequences would become a real challenge to all the conventional models. Alternatively, one should try to come up with an explanation for the large-scale biasing of the cluster distribution.

Deep Redshift Surveys – Periodicity?

Long term projects of measuring faint galaxy redshifts in very deep, narrow pencil beams have started producing exciting results. The original aim was to detect galaxy evolution and clustering evolution at high redshifts. While these aspects of the results are still inconclusive, the deep counts triggered a lively controvercy concerning the pattern of large-scale clustering itself. The longest published pencil (Broadhurst *et al.* 1990), extending to $\sim \pm 1000\ h^{-1}$Mpc toward the north and south galactic poles, reveals a periodic pattern of $\sim$ 10 h^{-1}Mpc-thick peaks separated by $\sim 100\ h^{-1}$Mpc voids. The first peak in the count to the north and the two first peaks to the south roughly coincide with the "great walls" seen in the slice surveys. But the most surprising result is the pronounced periodicity in this data, with a characteristic scale of $\simeq 130\ h^{-1}$Mpc separating neighboring superclusters and with very little shift of phase along the pencil. This data has been critisized by some as a statistical fluke, but its implications might be far reaching. For example, the detected scale may be associated with the natural scale introduced by cosmology – the horizon at the time of transition from radiation- to matter-dominated universe – provided that the universe is open ($\Omega \sim 0.1$). The "sharpness" of the peaks versus the "emptiness" of the voids may be a lesson in "biased" galaxy formation. Certain globally-isotropic Gaussian models can produce pencils as periodic as observed with a probability of a few percent, so this one pencil is not enough for rejecting the family of Gaussian models with great confidence (Kaiser and Peacock 1990; Stanhill *et al.* 1990). But this probability is on the order of 10% or less in any model that is homogeneous on large scales (including periodic lattices), so further pencils of similar extent should either be less periodic or else they pose a severe difficulty for all the standard models.

In summary, a rich body of data has been accumulating at an encouraging pace, and preliminary steps have been taken toward the confrontation of the data with theory. The current data indicates severe inhomogeneities in the mass distribution on scales of tens of megaparsecs, and in the distribution of galaxies on scales of hundreds of megaparsecs. This structure is not in direct conflict with the basic assumption of large-scale homogeneity, or with the observed isotropy of the microwave background, especially if one is willing to allow the galaxies (and clusters) to cluster more then the undelying mass. However, if the scale of inhomogeneity will continue to grow as our samples get bigger, or if the upper limits on $\delta T/T$ will continue to tighten below the 10^{-5} level, we will face a real crisis in our understanding of the universe.

Where do the specific scenarios stand? There are serious indications for more large-scale power than indicated by the popular CDM scenario that does so well on $\lesssim 10\ h^{-1}$Mpc scales, but despite the efforts made so far this scenario has not been ruled out very convinsingly yet, provided that the biasing factor is small (< 2, say). A better fit to the excessive structure on large scales may be provided by (less elegant) open universe models (e.g. Peebles 1987; Blumenthal *et al.* 1988), which could be dominated by (more conventional) baryons, (more contrived) $\sim 30eV$ neutrinos, or (even more contrived) hybrids of dark matter species. Unfortunately, there is no positive experimental clue yet for what the dark matter species might be. Cosmic strings cannot be ruled out yet based on the gravitational radiation effect on the millisecond pulsar (Bouchet and Bennet 1990), but this scenario became less popular as detailed simulations revealed fatal features, including over-fragmentation to subgalactic scales and failure to reproduce superclustering, except, possibly, for an ad- hoc combination of "wakes" and "hot" dark matter. The explosion scenario could make large superclusters of clusters, but it also seems to be in severe trouble because it suggests no obvious way for generating the observed large-scale coherent motions. Fortunatelly, with the current rate of accumulation of data, the constraints on theory promise to tighten significantly within the next few years.

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FORMATION OF GALAXIES AND LARGE SCALE STRUCTURE
(Sergei Shandarin)

A short review of this large and rapidly developing field of current cosmology is necessarily subjective and fragmentary. I will divide the topic into two sections: observations and interpretation, and N-body simulations and theory. Every work of course contains to some extent both parts so the assignment of some paper to a particular section might be subjective and contingent.

1 Observations and Interpretations

New confirmations of the reality of the filamentary or cellular large-scale structure in the spatial distribution of galaxies have been obtained. Bhavsar and Ling (1988) tested the reality of the filamentary features apparent to the eye in the distribution of galaxies, using a sample from the CfA redshift survey. Using the minimal spanning tree as a filament finding algorithm they found that the filaments are not merely due to visual bias is and chance alignments - they are real.

The search of the largest structures in the universe nicknamed the Great Attractor results in the claim that it is probably a real structure. The 900 galaxy survey by Dressler (1988) toward the apex of the large-scale streaming flow for ellipticals shows a substantial concentration of galaxies with discreet peaks at $V \sim 3000 kms^{-1}$ and $V \sim 4500 kms^{-1}$. The centroid of the distribution is found to be an $V \sim 4000 kms^{-1}$.

In some sense complimentary study carried out by Burns et al (1988) brought the evidence for the existence of a void in the Pisces-Cetus region. The void is nearly surrounded by a shell of galaxies and eight rich clusters with a diameter of about $4000 kms^{-1}$. It is compatible in size to the largest known void volume within Bootes.

Even more striking result was reported by Broadhurst et al (1990). Combining the redshift distributions observed in four distinct surveys at the North and South Galactic poles they found an excess correlation and apparent regularity in the galaxy distribution on a scale of $\sim 120 h^{-1} Mpc$.

The correlation analysis carried out for different samples of galaxies and acknowledged the main known correlation properties of the large-scale galaxy distribution continues to provide contradictory data concerning the details which can be illustrated by the results of three recent major studies. The Durham group (Stevenson et al 1988) using the objectively defined galaxy and cluster catalogues (COSMOS/UKST galaxy catalogue) supports the observation of a "break" from the power-law behaviour of the angular correlation function w_{gg} at angular scales corresponding to a spatial separation of $3 - 5 h^{-1} Mpc$, although the feature is only significant at the 2σ level. At larger scales ($\geq 6 h^{-1} Mpc$), w_{gg} shows no significant evidence of clustering. The Edinburgh group (Collins et al, 1989) calculated the angular two-point correlation function of galaxies at a depth of $b_j \approx 20$ for two regions of the Edinburgh/Durham southern galaxy catalogue came to the conclusion that the correlation function for a region $\sim 100 deg^2$ calibrated to high accuracy confirm a break from power-law corresponding to a physical scale $\sim 7 h^{-1} Mpc$. The first results on large-scale structure in the universe from a uniform survey of ≥ 2 million galaxies brighter than $b_j = 20.5$ constructed from machine scans of 185 UK Schmidt plates (Maddox et al 1990). Two-point angular correlation function shows a break from a power law at roughly the same physical separation as found by Groth and Peebles from their analysis of the Lick catalogue, but the present measurements decline much more gently from a power law on larger scales.

The analysis of the three-dimensional distribution of galaxies carried out by de Lapparent et al (1988) for the CfA redshift survey slices shows that the "average" statistical measures used to characterize the galaxy distribution are substantially more uncertain than previously estimated. The mean galaxy number density for the two strips is uncertain by 25$\sim$ $3 - 14 h^{-1} Mpc$ range the spatial two-point correlation function has a slope $\gamma \approx 1.6$ and a correlation length $s_0 \sim 7.5 h^{-1} Mpc$. On scales larger than $20 h^{-1} Mpc$ the correlation function is indeterminate.

The important question of the evolution of the structure was addressed in the work by Iovino and Shaver (1988). They showed that the evolution of the quasar-quasar correlation function is confirmed and appears to be relatively rapid (the correlation functions for $z \geq 1.5$ and $z \leq 1.5$ samples where compared), implying gravitational collapse on cluster scales.

The observations of the internal structure of galaxies are in general agreement with the popular theoretical concepts that galaxies and larger structures form in hierarchical clustering process in dark matter dominated universe. For instance, Rubin et al (1988) and Whitmore et al (1988) found a good correlation between the outer gradient of the rotation curve and the galaxy's distance from the center of the cluster, in the sense that the inner galaxies tend to have falling rotation curves, while the outer galaxies, and field galaxies, tend to have flat or rising rotation curves. Jedrzejewski and Schechter (1988) found the evidence for dynamical subsystems in elliptical galaxies, namely the reversal in the direction of rotation, which is difficult to explain with a simple model for the formation of an isolated galaxy. They proposed that the strong interaction between galaxies has taken place in the past.

2 N-body Simulations and Theory

N-body simulations play essential role in considerations of the problem of both galaxy and large scale structure formation. Addressing the question of possibility of the gravitational instability scenario to explain the formation of the largest structures found recently ("Great Walls") Park (1990) performed the largest N-body simulation of the structure formation in a biased Cold Dark Matter model. Simulating the motion of 128^3 particles in the cube of $307.2h^{-1}Mpc$ size he came to the conclusion that this model can explain such a structure quite easily.

Weinberg and Gunn (1990) came to the similar conclusion on the basis of their simulations of the large-scale structure using the adhesion model of the gravitational instability suggested recently by Gurbatov et al (1989). They conclude that gravitational instability of Gaussian density fluctuations with a Cold Dark Matter power spectrum can generate structure comparable in linear extent to the largest existing redshift surveys.

Jones et al (1988) showed that the clustering structures in the observed universe and in numerical simulations are not well represented by a homogeneous measure on a fractal. They proposed instead that a good description of these clustering structures is given by "multifractals" - fractals having more than one scaling index.

Gott III et al (1987) measured the topology (in terms of the mean genus per unit volume) of the evolved mass distribution and "biased" galaxy distribution in the Cold Dark Matter models showed that it was consistent with the topology of the observational sample of galaxies.

The problem of the primeval galaxies seems to be reconciled with the major scenarios of the structure formation. According to Silk and Szalay (1987) primeval galaxies are envisaged as a collection of many interacting and merging clumps, attaining a peak luminosity that is an order of magnitude below that achieved in models in which galaxy formation is initiated abruptly. The new model of galaxy formation suggested by Boron and White (1987) also assumes that protogalaxies should be considerably fainter than was previously predicted. Galaxy formation could continue until $z = 1-2$ without serious conflict with the reported null results of primeval galaxy search. The properties of the faintest object in recent galaxy count studies are consistent with their being primeval galaxies at $z = 2 - 3$.

It has been long known that one of the major problems of the Hot Dark Matter model is the timing problem for galaxy formation, i.e. the inferred young age for the large-scale structure versus the observationally indicated older age of galaxies and quasars. Broun et al (1988) conclude that the hypothesis of "antibiasing" requiring that galaxies form preferentially in the flat "pancakes" relative to the denser "filaments" and compact clusters can solve the problem.

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ACTIVE GALACTIC NUCLEI IN COSMOLOGY

(P. A. Shaver)

Many papers have been written in this burgeoning field over the last three years, but with the limited space available here it is only possible to provide a broad overview with a representative sample of references, which hopefully will suffice to lead the reader to other relevant publications. A number of useful proceedings have been published in this area over the last few years, including the following: Observational Cosmology (1987, eds. A. Hewitt et al.; Reidel); High Redshift and Primeval Galaxies (1987, eds. J. Bergeron et al.; Editions Frontiers); QSO Absorption Lines: Probing the Universe (1988, eds. C. Blades et al.; Kluwer); Large Scale Structures of the Universe (1988, eds. J. Audouze et al.; Kluwer); The Post-Recombination Universe (1988, eds. N. Kaiser & A.N. Lasenby; Kluwer); Optical Surveys for Quasars (1988, eds. P. Osmer et al.; Astron. Soc. Pacific); Active Galactic Nuclei (1989, eds. D.E. Osterbrock & J.S. Miller; Kluwer); Gravitational Lenses (1989, eds. J.M. Moran et al.; Springer); Large Scale Structure and Motions in the Universe (1989, eds. M. Mezzetti et al.; Kluwer); The Epoch of Galaxy Formation (1989, eds. C.S. Frenk et al.; Kluwer); Gravitational Lensing(1990, eds. Y. Mellier et al.; Springer).

Work continues on radio source counts (e.g. Katgert et al., 1988; Oort et al., 1988; Grueff, 1988; Sokolov, 1988; Condon, 1988), and it appears that the flattening at microjansky flux densities may be due to an evolving population of starburst galaxies at intermediate redshifts (Danese et al., 1987; Thuan & Condon, 1987; Kellermann & Fomalont, 1988). At high flux densities it is now found that the sources are in fact not isotropically distributed over the sky, but rather concentrate towards the supergalactic plane (Shaver & Pierre, 1989; Shaver, 1990). The evolution of radio sizes and structures has been further explored (e.g. Oort et al., 1987; Oort, 1988; Barthel & Miley, 1988; Barthel et al., 1988; Singal, 1988; Hutchings et al., 1988; Kapahi, 1989; Neff et al., 1989). Redshift and luminosity dependences can be separated for radio galaxies, and it is found that radio quasars at high redshifts are both smaller and more distorted. Several authors have studied orientation effects, apparent super- luminal motions, and unified beaming models (Pearson & Zensus, 1987; Morisawa & Takahara, 1987; Laing, 1988; Barthel, 1989; Kellermann et al., 1989; Jackson & Browne, 1990); Cohen et al. (1988) have shown that the proper motions are anticorrelated with redshift as expected in a standard Friedmann cosmology, and Rust et al. (1989) have used models of superluminal radio sources to estimate cosmological parameters.

Searches for high-redshift radiogalaxies and quasars have been highly successful over the last few years. The presence of an ultra-steep radio spectrum turns out to be a good indicator of a high redshift (Chambers et al., 1987), and radio galaxies have now been found at redshifts as high as 3.4 (Lilly, 1988) and 3.8 (Chambers et al., 1990). For quasars, searches employing red-sensitive slitless spectroscopy and multicolour photometry have resulted in a burst of discoveries of quasars at $z > 4$ (Warren et al., 1987; Schneider et al., 1989a); the highest redshift known at present is 4.73 (Schneider et al., 1989b). The space density of typical quasars appears to decrease above $z \sim 2$ (Warren et al., 1988; Schmidt et al., 1988; Schmidt, 1989), supporting the notion of a "quasar epoch" centred at $z \sim 2$, but the space density of the most luminous quasars apparently remains roughly constant at $z > 2$ (Mitchell et al., 1990).

The very existence of galaxies and quasars at such early times poses difficulties for theories of galaxy formation (Efstathiou & Rees, 1988; Oort, 1988). It has been suggested that at least some of them in fact contain old stellar populations (Dunlop & Longair, 1987; Lilly, 1988, 1989; Lilly & McLean, 1989). Others argue that many of the observed high-redshift radio galaxies are young (e.g. McCarthy et al., 1987b; Chambers & Charlot, 1990; Bithell & Rees, 1990), particularly the prominent optical and infrared components which are found to be aligned with the radio axes (McCarthy et al., 1987a; Chambers et al., 1987; Baum & Heckman, 1989; Rees, 1989; de Young, 1989; Eisenhardt & Chokshi, 1990; Eales & Rawlings, 1990). Sanders et al. (1988) have suggested that quasars may be born as ultraluminous infrared galaxies hidden in dusty cocoons; megamaser emission could arise due to amplification of the radio nuclei of such objects (Crusius & Schlickeiser, 1988; Baan, 1989). Work con- tinues on the overall evolution of radiogalaxies and quasars (e.g. Boyle et al., 1987; Marshall, 1987; Koo & Kron, 1988; Heisler & Ostriker, 1988; DasGupta et al., 1988; Blandford, 1989; Cavaliere et al., 1989; Phillipps et al., 1990; Guiderdoni & Rocca-Volmerange, 1990).

Studies of the environments of active galaxies and quasars provide information related to both the origin of the nuclear activity and large scale structure. It is now clear that radio galaxies and quasars have relatively rich environ- ments and often show signs of interaction (Yee & Green, 1987; Yee, 1987; Prestage & Peacock, 1988; Boyle et al., 1988; Yates et al., 1989; Smith & Heckman 1990; Hutchings & Neff, 1990). Furthermore, the environments of both radio galaxies and radio-loud quasars increase markedly in richness towards higher redshifts ($z \sim 0.8$), although this is apparently not true for radio- quiet quasars. Clustering on scales of $< 10h^{-1}$ Mpc has been detected amongst radio galaxies at low redshifts (Peacock et al., 1988) and amongst quasars at higher redshifts (e.g. Shanks et al., 1987; Iovino & Shaver, 1988; Shaver, 1988; Kruszewski, 1988; Chu & Zhu, 1988; Shanks et al., 1988; Iovino et al., 1989; Crampton et al., 1989), and there is some evidence that the clustering increases with decreasing redshift. Studies of the fluctuations of the micro- wave and X-ray backgrounds provide limits on the clustering of AGNs at high redshifts (Franceschini et al., 1989; Meszaros & Meszaros, 1988; Barcons & Fabian, 1988, 1989; de Zotti et al., 1990). Such work may provide direct evidence regarding the evolution of structure, and it may have some relevance to the evolution of the space density of quasars if quasar activity is triggered by interactions (e.g. Carlberg, 1990).

A great deal of work has been focussed on gravitational lensing. A considerable variety of new candidate lenses has been found, including the four-image "clover leaf" H1413+117 (Magain et al., 1988), two possible "Einstein rings" (Hewitt et al., 1988; Langston et al., 1989), and perhaps some 3C radio galaxies (le Fevre & Hammer, 1990), bringing the total number of known likely gravitationally lensed AGN images to over ten. Some of these may imply very large mass-to-light ratios for the lensing objects (e.g. Hewitt et al., 1987; Hewett et al., 1989). The first microlensing event has been found in the Q2237+0305 system (Irwin et al., 1989), demonstrating the potential for obtaining information on the mass function of objects (dark or luminous) in the lensing galaxy. And measurements of possible time delays between variations in the two images of Q0957+561 have been reported in the radio, optical, and ultraviolet (Lehar et al., 1989; Vanderriest et al., 1989; Altner & Heap, 1988); such time delays may in principle be used to determine the Hubble constant. The incidence of gravitationally split images is somewhat higher than expected (Narayan & White, 1988; Blandford, 1990), as is the strength of statistical gravitational lensing which has been detected by Fugmann (1988, 1989) and Webster et al. (1988) in the form of an excess of (presumably foreground) galaxies near high-redshift quasars; the possible cause of the relatively large magnitude of this latter effect has been discussed by Narayan (1989), Kovner (1989), and Schneider (1989). The influence of gravitational lensing on the number counts of distant objects has been discussed by several authors (Schneider, 1987; Kayser & Refsdal, 1988; Rix & Hogan, 1988; Isaacson & Canizares, 1989; Ostriker & Vietri, 1990). Possible applications of gravitational lensing of distant quasars in connection with cosmological parameters, cosmic strings and large scale structure have been explored by Gott et al. (1989), Webster & Hewett (1988), and Turner (1987).

Quasar absorption lines provide a powerful tool to explore the properties and distribution of objects scattered along the intervening line of sight. The high column density Lyman-limit, damped Lyman α and MgII systems have been further investigated in a few surveys (Lanzetta et al., 1987; Sargent et al., 1988, 1989; Turnshek et al., 1989; Petitjean & Bergeron, 1990). The damped Lyman α systems, thought to arise in high-redshift protogalactic disks, occur more frequently along the line of sight than do normal spirals, and dominate the baryon content of the universe at z = 2-3 (Wolfe, 1988); in one case a lower limit of 8 kpc has been set on the size (Briggs et al., 1989). Galaxies have been identified with several of the MgII absorbers (Bergeron, 1988), but no Lyman α emission has been found associated with the damped systems, implying very low star formation rates (Smith et al., 1989). Detailed studies of some of these low-ionization systems reveal very low metallicities and dust-to-gas ratios (Meyer & York, 1987; Pettini & Hunstead, 1990; Rauch et al., 1990; Sargent et al., 1990), and very low CO abundance, but the probable presence of molecular hydrogen (Foltz et al., 1988; Levshakov et al., 1989). Further surveys have also been made for CIV absorption systems (Sargent et al., 1988; Steidel, 1990; Barthel et al., 1990), with the principal new finding that the number of CIV systems per unit redshift increases with decreasing redshift, apparently reflecting an increase in heavy element abundances with cosmic time (Steidel et al., 1988); from statistics of MgII systems it appears that the density of absorbers then decreases again below z = 1 (Sargent et al., 1988). The concentration of CIV absorbers near the quasar emission redshifts was further examined (e.g. Foltz et al., 1988), and the possibility that gravitational lensing may bias the absorption-line statistics was explored by Thomas & Webster (1990). Sarazin (1989) suggested that X-ray absorption lines may be observable in the spectra of quasars located behind clusters.

The exact nature of the low-column density Lyman α absorbers remains unknown. Tytler (1987) suggested that the different absorbers, heavy-element and Lyman α, may in fact comprise a single population. Possibilities recently discussed specifically for the Lyman α absorbers include pressure-confined clouds, gravitationally-confined CDM minihalos, relics of primordial density fluctuations, protogalactic pancakes, shock fragments, and gas-rich dwarf galaxies (Hogan, 1987; Vishniac & Bust, 1987; Bond et al., 1988; Tyson, 1988; Baron et al., 1989; Ikeuchi et al., 1989; Babul, 1990; McGill, 1990). Hunstead & Pettini (1990) suggest on the basis of high resolution spectroscopy that the Lyman α clouds may be largely neutral with temperatures < 5000K. And spectroscopy of the Lyman α forest in the two images of the gravitational lens pair UM 673A,B shows that the Lyman α clouds are larger than $10h^{-1}$ kpc (Smette et al., 1990).

Clustering of absorption systems provides further information both about the absorbers themselves and about the large-scale distribution of matter at high redshifts. Both CIV and MgII systems show significant line-of-sight clustering on velocity scales up to 600 km s^{-1}, with a high amplitude compared with galaxy clustering today (Steidel, 1990; Petitjean & Bergeron, 1990). By contrast the Lyman α absorbers exhibit relatively little clustering, and voids appear not to be commonplace in their distribution (Crotts, 1987; Pierre et al., 1988; Bechtold & Shectman, 1989; Duncan et al., 1989; Barcons & Webb, 1990). Cross-correlation of absorption systems in the spectra of pairs or groups of quasars can be a powerful tool in studying large scale structure at high redshifts (Cristiani & Shaver, 1987; Crotts, 1989); the evidence for a possible very large structure in front of one such pair has been discussed (Cristiani et al., 1987; Robertson, 1987; Sargent & Steidel, 1987; Jakobsen et al., 1988).

There is increasing interest in the ionization of the high-redshift intergalactic medium, and what it tells us about populations at those epochs. Steidel & Sargent (1987) set a new, extremely stringent limit on the density of intergalactic neutral hydrogen using high resolution spectra of the Lyman α forest. The "inverse" or "proximity" effect - the reduction in the density of Lyman α absorption lines near the quasar redshift - was further explored (Barcons & Fabian, 1987; Hunstead et al., 1988; Bajtlik et al., 1988); if indeed it is due to enhanced ionization near the quasar, it is possible to infer the back- ground of ionizing photons. It seems clear that the known quasars are insuf- ficient to ionize the high-redshift intergalactic medium (Shapiro & Giroux, 1987; Donahue & Shull, 1987; Carswell et al., 1987; Miralda-Escude & Ostriker, 1990). The possibility that there are many more quasars at high redshifts which are obscured from view by intervening dusty galaxies has been discussed (Heisler & Ostriker, 1988; Weedman, 1987; Shaver, 1987; Boyle et al., 1988; Fall et al., 1989; Najita & Silk, 1990), and other possible sources of ionizing radiation have been explored, including star-forming galaxies and photino decay (Shapiro et al., 1987; Sciama, 1988; Steidel & Sargent, 1989; Songaila et al., 1990).

Many papers have been written on the still unsolved problem of the origin of the X-ray background. Whether or not known populations of AGN can account for all of the XRB remains a matter of debate (e.g. Giacconi, 1987; Hamilton & Helfand, 1987; Young & Yu, 1988; Schwartz & Tucker, 1988; Fabian et al., 1989; Setti & Woltjer, 1989; Persic et al., 1989; Barcons, 1990; Mereghetti, 1990)), and other possible populations of objects at early epochs have been proposed (Boldt & Leiter, 1987; Fabian et al., 1988; Zdziarski, 1989; Subrahmanyan & Cowsik, 1989; Fabian et al., 1990). If discrete sources do in fact make up the XRB, then studies of fluctuations in the XRB can be used to study their clustering properties at the relevant high redshifts, and compared with the known clustering of galaxies and quasars at low and intermediate redshifts (Meszaros & Meszaros, 1988; Barcons & Fabian,1988, 1989; de Zotti et al., 1990).

Active galaxies and quasars, by virtue of their high redshifts, are well suited for the continuing investigation of the nature of the redshift in particular and possible distinctions between different cosmologies in general (e.g. Arp, 1987; Crawford, 1987; Arp, 1988, 1989; Woltjer, 1988; Cristiani & Shaver, 1988; Das & Sivaram, 1988; Laurent et al., 1988; Narasimha & Narlikar, 1989; Segal, 1990). Two particular aspects of continuing interest are quasar-galaxy associa- tions with discordant redshifts (Sulentic & Arp, 1987; Sulentic, 1988; Fagundes, 1989; Fang et al., 1989; Burbidge & Hewitt, 1989; Arp, 1990; Arp & Burbidge, 1990) and redshift periodicities and quantization (Cocke & Tifft, 1989; Chu & Zhu, 1989).

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THE COSMIC MICROWAVE BACKGROUND RADIATION

(R.B. Partridge)

The cosmic microwave background radiation (CBR) discovered 25 years ago by Penzias and Wilson (1965) is generally accepted as a relic of the hot big bang (Dicke et al., 1965). If so, it should be essentially isotropic and have a blackbody speatrum. We turn to the current observational evidence supporting this view after a brief review of progress on the theoretical side from 1987 to 1990.

I. Progress in Theory

Since the early work of Thorne (1967), Peebles and Wilkinson (1968), Silk (1968) and Hawking (1969), it has been recognized that the CBR will no be perfecrtly isotropic. The motion of the observer or the anisotropic expansion of the Universe will introduce anisotropy on large angular scales. Perturbations in the density or velocity of the matter which last interacted with the radiation will introduce fluctuations on smaller angular scales. The latter have been extensively investigated by Bond and Efstathiou (1987), Juszkiewicz et al. (1987), Gouda et al. (1987), Vittorio et al. (1989), Cole and Efstathiou (1989), and Martinez-Gonzales and Sanz (1989), among others. The review by Bond (1988) shows that the predicted amplitude of fluctuations $\Delta T/T_0$ in many models exceeds the observational upper limits discussed below. Adding cold dark matter or bias helps bring theory into better agrrement with the observations. There have also been detailed models (Vishniac, 1987) of $\Delta T/T_0$ fluctuations introduced by explosive galaxy formation; in this scenario, the CBR last interacts with matter at redshifts much less than the redshift of recombination, $z \sim 1000$. Larger amplitudes at smaller scales are predicted. Finally cosmic strings may introduce fluctuations in the CBR (Kaiser and Stebbins, 1984); in this case, the statistics of the fluctuations are non-gaussian. Maps of these non-gaussian fluctuations have been published by bouchet et al. (1988). Most of the theoretical work on the spectrum of the CBR in the past 3 years has been devoted to explanations of departures from a blackbody specturm at high frequencies (or $\lambda \leq$ 1 mm). See papers by Hayakawa et al. (1987), Daly (1988), Lacey and Field (1988), Fukugita and Kawasaki (1990), Adams et al. (1989) and Wang and Field (1989) among others. For reasons laid out in section IV below, I will not consider these further.

II. Searches for Anisotropy on Small Scales

Searches for CBR fluctuations on $1' - 10'$ scales have been pushed to new levels of sensitivity by a group at Cal Tech (Readhead et al., 1989). At $\lambda = 1.5$ cm and $\theta = 7'.5$, they find $\Delta T/T < 1.7 \times 10^{-5}$, currently the tightest limit on CBR anisotropies on any angular scale. On smaller angular scales, arrays of radio telescopes are used to probe the CBR. Observations at 6 cm (Fomalont et al., 1988; Martin and Partridge, 1988 and 2cm (Hogan and Partridge, 1989) show $\Delta T/T \leq 1.5 \times 10^{-4}$ at $\theta = 18''$and$\Delta T/T \leq 6 \times 10^{-5}$ at $\theta = 60''$. Work in progress at $\lambda = 4$ cm (again at the VLA; Fomalont et al., 1990) is expected to have ~ 3 times the sensitivity of earlier work on scales $10'' - 40''$. Recently, interest has turned to angular scales of $\sim 1° - 10°$. While the report of a detection of CBR fluctuations by Davies et al. (1987) is now regarded with some skepticism, other workers are pushing limits to the few $\times 10^{-5}$ level (e.g., Lubin, 1990). The most sensitive work exploits the 3mm and

9mm atmospheric windows; in addition it has been found that the South Pole is an excellent observing site for CBR studies. At arcminiute scales and below, we are approaching fundamental technological levels. There is more room for improvement on scales > 10′, and there is good reason to expect interesting new results in the next few years.

III. Searches for Anisotrophy on Large Scales

Observations from balloons (Boughn et al., 1990; Page et al., 1990) and rockets (Halpern et al., 1988) have continued. The dipole moment of the CBR is now known to a few percent precision: $T_1/T_0 = (1.20 \pm 0.03) \times 10^{-3}$. Confirming earlier work by the Soviet satellite Relict (Klypin et al., 1987), no evidence for a quadrupole moment has been seen: $T_2/T_0 \leq 2 \times 10^{-5}$. The launch in November 1989 of the COBE satellite (see V below) will have a major impact on our knowledge of the large- scale distribution of the CBR. In particular, its multi- wavelength observations will permit a better correction for anisotropic emission by the Galaxy.

IV. Possible Distortions in the Spectrum of the CBR

In 1988, Matsumoto et al. announced the results of a carefully designed rocket experiment to measure the CBR speatrum at $\lambda \leq$ 1mm. An apparent distortion, the "submillimeter excess" at $1000 \leq \lambda \leq 400\mu$, was reported. Observations at longer wavelength (e.g., Johnson and Wilkinson, 1987; Smoot et al., 1988; Bersanelli et al., 1989) in general remained consistent with a 2.73-2.75 K blackbody. High precision measurements based on the thermal excitation of interstellar CN molecules (Crane et al., 1989; Meyer et al., 1989, Palazzi et al., 1990) showed T_0 = 2.75 -2.79 at 2.64mm and 2.83 ± 0.7K at 1.32mm. The precision of the 1.32mm measurement and of a broad-band bolometric measurement by Halpern et al. (1988) was not quite good enough to confirm or negate the submillimeter excess. The COBE satellite, to which we turn next, has apparently settled the issue.

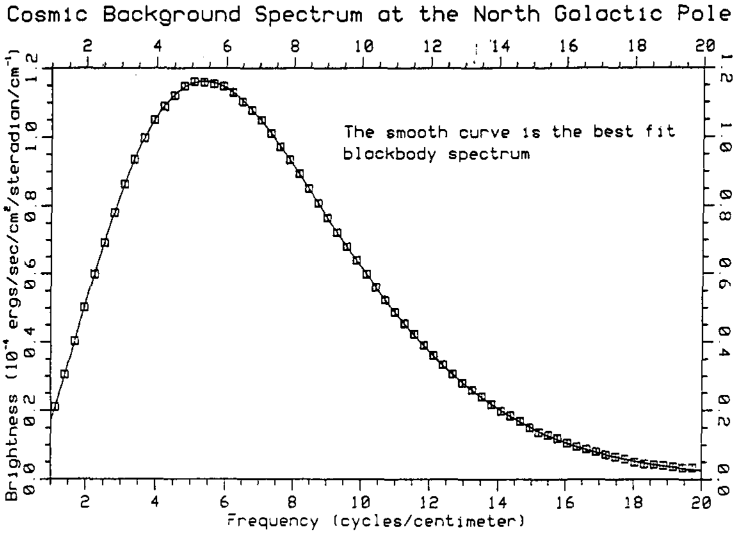

Fig. 1 COBE measurements of the CBR, with nominal 2% error boxes, superimposed on a 2.735K Planck curbe (reproduced courtesy of J.C. Mather et al. and the Astrophysical Journal).

V. COBE

The Cosmic Background explorer satellite, launched by NASA on 18 November, 1989 was designed to measure and map microwave and ir backgrounds from λ = 1cm to $\lambda = 1\mu$. It carried three instruments: (1) an absolute far ir and microwave photometer, (2) a set of microwave radiometers to map the CBR at three different wavelengths and (3) a broad band instrument to measure diffuse ir backgrounds. At the time of this writing, only preliminary data are available from the second and third instruments (see summary by Schwartzschild, 1990). The dipole component was readily detcted by the three mapping radiometers, and measured values of T_1 are in good agreement with earlier work. Pixel to pixel variation in T_0 on scales of 7° appears to < 3×10^{-4}K Smoot, private communication). More details will be presented at the General Assembly. The major contribution of COBE to date is its measurement of the CBR spectrum in the interval 1cm< λ < 0.5mm shown in fig. 1 (Mather et al., 1990). The data points with nominal 2% error bars are shown superimposed on an exact Planck curve for $T_0 = 2.735$ K. The agreement is superb: there is no room for appreciable destortions of the CBR spectrum. The absence of distortions in turn sets interesting constraints on theories of galaxy formation.

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PRIMORDIAL NUCLEOSYNTHESIS

(Hubert Reeves)

Since 1987, important progresses in the subject of big bang Nucleosynthesis (BBN) have been made in three area: astronomical data, laboratory data and theoretical physics. At the same time the success of BBN in accounting for the observed light nuclide abundances has been become an important guiding tool in the study of unconventional models of cosmology and particle physics (these models are required to preserve the successes of BBN).

Astronomical data

Recent observations of Li and Be in highly metal poor stars (Pop II) can be used to convincingly show taht Li in these stars in neither of Galactic Cosmic Ray origin nor of stellar origin (1-12). Thus its abundance can be taken as a measure of BBN yield. Despite extensive calculations and modeling (13-18) the fractional depletion of lithium in these stars is still a matter of some debate. Following the critical analysis of Michaud and Charbonneau the range from $2 \times 10^{-10} <{}^7\mathrm{Li/H}< 5 \times 10^{-10}$ can be recommended, with 10^{-9} as strong upper limit. New data have been obtained on ^{4}He abundance in minimally stellar-processed matter(19-21) The uncertainties are still largely a matter of debate and vary amongst authors. As a prudent estimate, I would keep the full range from $Yp = 0.225$ to 0.245 with 0.250 as a strong upper limit. The main problem with D and ^{3}He is the extrapolation from present and protosolar values to the time of BBN. Models of galactic evolution based on abundances of chemical elements are needed to evaluate the depletion of D from its primordial value (22-24). It is not clear that they are already reliable enough to give an accurate answer to this question. Recent suggestions that infall of extragalactic matter is required in these models is of great interest in this respect. The infalling matter is expected to contain largely primordial D abundance, thereby decreasing the effective D depletion during galactic life.

Laboratory data

Until recently, the number of neutrino flavors was one "parameter" of BBN. The theory could account for the observations if this number was smaller than five. The LEP results (25) have confirmed this prediction : the number is 3.2 = -0.2.. Cold nuetron experiment (26) have given an improved measure of the neutron lifetime (another important "parameter" of BBN) The value is : 890 ± 4sec; (corresponding to 10.3 minutes). The possible effects of the quark-hadron phase transition (around 200 MeV) on the BBN yields of the light elements (around 0,1 MeV) have been investigated by several groups (27-34). This transition is presently believed to be "weakly first order" This implies the possibility of overcooling of the quark-gluon plasma, leading to density inhomogeneities of baryonic matter. These inhomogenities could persists until the period of BBN. Neutrons could diffuse from the high density to the low density regions. creating inhomogeneities in n/p ratio. These inhomogeneities are likely to modify the BBN yields from the values calculated in the homogeneous density framework (the "standard" case). (35) Despite vigourous efforts in QCD network calculations on a lattice, (36-39) the crucial parameters of the Q-H phase transition are still poorly known- The exact value of the critical phase temperature (affecting the strength of the density contrasts) and the bubble surface energy density (affecting the interbubble distances) can not yet be determined satisfactorily. These parameters are needed for the computation of BBN yields. In view of these uncertainties BBN yields have been computer for extended sets of parameters corresponding to the uncertainties in the physics of the Q-H transition (40-48). Recent calculations includes the very important effects of neutron back diffusion during BBN (49-53). The results of the different groups are in reasonable agreement. Compared to the homogeneous density case, the net effect is a widening of the range of baryonic density compatible with the ovserved abundances. The baryon density could amount to as little as one percent or as much as twenty per cent of the critical density. However the observed abundances of both 4He and ^{7}Li appear to exclude that the universe could be closed by baryons. (It has recently been proposed that later homogenisation could reduce the ^{7}Li yield).

BBN as a tool for new physics

It seems reasonable at this point to require that new models of particle physics or cosmology should not lead to important modifications of the computed BBN yields, out of the range of compatibility with the observations. As an example, Kaluza-Klein type of models, introducing new space dimensions, may imply a time variation of the laboratory coupling "constants". Such models have to gibe reasons why these constants appear to haave remained unchanged since the period of BBN (as required for the success of BBN). This requirement, called "stabilisation of compactification"; (54) is a constraint to be met by all superstring theories with extradimensional space.

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THE COSMOLOGICAL PARAMETERS
(V. Trimble)

A homogeneous, isotropic, general relativistic model of the universe is completely specified by numerical values of H (Hubble parameter, normally given in km/sec/Mpc), Ω (the density in units of the critical density, $\rho_c = 3H^2/8\pi G$), and Λ (the cosmological constant, units of vacuum energy density). Additional parameters derivable from these areq_0 (the deceleration parameter), T_0 (the present age), and the radius of curvature (normally in units of H^2R^2, so that k = +1, -1, and 0 are positively curved, negatively curved, and flat space). Rather little progress in measuring definitive values for and of these has been made since the last trienniel Commission report[1]. Two recent conference proceedings have addressed values of T_0^2 and the other parameters[3].

Mesaurements of H based on step-by-step calibrations of distance criteria continue to yield values between 50 and 100 km/sec/Mpc, depending on who does the stepping[4]. Recent additions to the set of calibrators include novae in the Virgo cluster[5], diameters of HII regions[6], and supernovae[7]. The light curves of distant supernovae can, in addition, distinguish true expansion from tired light redshifts[8]. Innovative, and not yet fully developed, distance indicators include the shape of $N(L)$ for globular clusters[9], time delays in gravitational lenses (hopeless unless you know the lens structure independently[10]), N(L) for planetary nebulae[11], X-ray line emission vs. absorption in clusters[12], the Sunyaev-Zeldovich evfect (3K scattering vs. X- ray emission in clusters), and counting statistics in measurements of galactic surface brightness (the number of stars contributing to surface brightness is nearly linear in total luminosity, so bright galaxies look smoother). Preliminary applications of these last two yielded H = 24 and 88 km/sec/Mpc[13]. Issues of Malmquist bias and the dependence of the Tully-Fisher relation (line velocity width vs. galaxy luminosity) on galaxy type continue to bedevil traditional methods[14]. Nor do we yet know the distance at which Hubble flow truly begins to dominate peculiar motions.

The determination of Ω from dynamics of galaxies and clusters continues to yield values below unity[15], apart from the IRAS galaxy sample[16], but always contingent on some assumption about the relation of light to mass fluctuations. A critical density in gravitational radiation at wavelengths from pc to 300 Mpc can be ruled out from non-detection of effects on pulsar timing, the microwave background, and nucleosynthesis[17]. Limits on the density in baryonic material from Big Bang nucleosynthesis can be Stretched via inhomogeneous nucleosynthesis or decaying dark matter from the canonical $0.1\rho_c$ up to $0.3\rho_c$ or thereabouts, but excess lithium production probably rules out $\Omega = 1$ in baryons[18], unless significant light element production takes place elsewhere[19]. Severe constraints, though somewhat difficult to interpret, come from the need to form galaxies without introducting excessive fluctuations into the microwave background radiation[20]. A self-consistent model of galaxy formation and the resulting Doppler velocity distribution on various scales has not yet been achieved but may eventually prove the best measure of Ω. Certain forms of inflation may solve the horizon and monopole problems without producing $\Omega = 1$.[21]

The chief motivation for considering non-zero Λ remains[22] the desire to reconcile $T_0 \leq 10$ Gyr implied by $H \geq 65$ and $\Omega = 1$ with ages of globular clusters[23] and radioactive products of nucleosynthesis[24] ($\geq$ 14 Gyr for both). Several alternative reconciliations have proven illusory. A new radioactive chronometer (the near-constancy of Nd/Th in G dwarfs of various ages[25] which seemed to say that nucleosynthesis began less that 9.6 Gyr ago stretches to 9-20 Gyr for a range of possible chemical evolution models[26]. Shortening lifetimes of globular cluster stars by factors up to two[27] via extensive main-sequence mass loss falls afoul of the resulting depletion of surface lithium abundances below those observed both in the sun[28] and in halo stars themselves[29]. And ages near 10 Gyr for the oldest white dwarfs[30] and open clusters[31] may be measuring the time scale for galactic disk formation at R = 8.5 kpc rather than for the galaxy as a whole. Shortening stellar lifetimes up to 30% via the effects of weakly interacting massive particles[32] cannot presently be ruled out. Of the other parameters, q derived from a Hubble diagram at large redshift is more sensitive to galactic evolution than to cosmological model[33], and previously-reported evidence for space being essentially flat, from number counts of galaxies, also turns out to be vulnerable to undertainties in galactic evolution [34], though a greatly improved data sample might overcome the problem[35].

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