COMMISSION 47: COSMOLOGY

President : Jayant V. Narlikar (India)
Vice Presidents : A. Szalay (USA), P. Shaver (Germany)
Organizing Committee : R.B. Partridge (USA : Past President and President, Division VIII), R. Bond (Canada), J. Einasto (Estonia), M. Geller (USA), D. Jauncey (Australia), Y. Kozai (Japan), J. Peacock (UK), A. Wolfe (USA), Y. Chu (China)

INTRODUCTION

J.V. NARLIKAR
Inter-University Centre for Astronomy and Astrophysics
Post Bag 4, Ganeshkhind, Pune - 411 007

The report that follows gives glimpses into the enormous amount of work in cosmology over the past three years, both in theory and in observations. It is impossible to do justice, within the space allotted, to all the exciting work and some important topics like structure formation could not be covered. Nevertheless, the contributors to different sections have done a conscientious job and I thank them all. Some of them had to step in to fill the gaps at short notice.

While COBE had dominated the previous triennial, the present one saw the HST come into its own. Thus, the key project of measurement of Hubble's constant has begun to show results, putting the theoreticians on the defensive. The work on discrete source population including surveys and tests and attempts to quantify evolution at high redshifts are in full swing. This report on the early universe highlights theoretical models including inflation, as well as observations of relic radiation and relic nuclei. The radiation backgrounds at microwaves as well as at other wavelengths have also been reviewed.

The report could have been augmented further by models and simulations of large scale structure. It does describe, however, the powerful tool of gravitational lensing for detecting dark matter. A short section at the end describes a revival of alternative cosmologies now that observational constraints on the big bang models are getting tighter.

During the triennial 1993-96 the Commission sponsored the IAU Symposium 168 entitled *Examining the Big Bang and Diffuse Background Radiations*, which was held concurrently with the IAU General Assembly at the Hague.

I close with the hope that with the HST and Keck on the line and the GMRT soon to come into operation, the report of the next triennial will be even more exciting.

I. Appenzeller (ed.), Reports on Astronomy, Vol. XXIIIA, 477–496.

DISCRETE SOURCE SURVEYS (1993-96)

GOPAL-KRISHNA
National Centre for Radio Astrophysics, TIFR
Post Bag 3, Ganeshkhind, Pune - 411 007
&
SOMAK RAYCHAUDHURY
Inter-University Centre for Astronomy and Astrophysics
Post Bag 4, Ganeshkhind, Pune 411 007, INDIA

The last three years have witnessed an immense proliferation of activity in this field, a snapshot of which is provided in this brief account which focuses on the surveys directly relevant to cosmological studies. The status prior to 1993 has been summarized elsewhere[1].

1. Radio Surveys

Two large-area sky surveys, set to detect millions of sources, were launched at λ=20 cm using the *VLA*. The *FIRST* survey ($S \geq 1$ mJy) provides morphological information for $\geq 2''$ sources, as well as optical identifications for ~15% of them[2]. The *NVSS* survey[3] would map the entire sky at $\delta \geq -40°$, with a 45″ beam to a limit of 2.5 mJy/beam. At longer wavelengths, the *WSRT* is being used to carry out the *WENSS* survey[4], to map at λ =92 cm the entire sky north of δ=30° with an 1′ beam to 15–20 mJy/beam.

A large part (2.5 sr) of the southern sky has been surveyed with the *Parkes* telescope at 5 GHz, the survey limit varying with δ between ~20-50 mJy/beam (the *PMN Survey*)[5–6]. Regions around the north ecliptic pole has been mapped[8] at 1.5 GHz (29 deg^2) using the *VLA*[7], and at 151 MHz with the *CLFST* (50 deg^2). The *5C13 Survey*[9] has brought the number of known 0.4 GHz sources to 3220 (including 5C sources). A machine readable version of the Rees 38 MHz Survey *("8C")* has been published, with revised source positions[10].

The *Green Bank* 5 *GHz* survey (~ 55000 sources, ≥25 mJy) has provided evidence for clustering of radio sources[11]. The region of the *Cambridge-Cambridge Serendipity Survey* has been imaged with the *VLA* at λ=20 cm, showing that the X-ray luminosity functions of radio-loud and radio-quiet AGN have undergone similar cosmological evolution[12]. An ongoing *VLBI* survey[13] for superluminal motion in AGN has raised the prospects of constraining the cosmological parameters H_0 & q_0.

2. Near and Far-Infrared Surveys

The *IRAS Bright Galaxy Survey* has been extended to cover 83% of the sky[14] to a flux limit of 5.24 Jy at λ=60 μ. The near-infrared (K-band) luminosity function of optically selected field galaxies[15] was found to have a number-magnitude relation consistent with no-evolution models. Deeper surveys, using the *Keck* and *UKIRT* telescopes are being carried out in order to study the cosmological evolution of the K-band selected galaxy population from their source counts[16–19].

3. Ultraviolet Surveys

The *All-sky Survey* with the *EUVE* observatory has yielded a catalogue of 410 'point' sources of far-UV emission (100-600Å), for which source counts were derived and plausible UV/X-ray counterparts identified in 90% of the cases[20]. By reprocessing an all-sky survey carried out with the all-sky camera on board *ROSAT*, a catalogue of 479 extreme-UV (60-140Å, 112-200Å) sources has been compiled[21]. A deep UV catalogue, containing 4698 discrete sources has been built from observations with the telescope *FAUST*[22], covering 4.4% of the sky to a flux limit of $\sim 10^{-14}$ erg s^{-1} cm^{-2} Å^{-1} in the range 1400-1800Å.

4. X-ray Surveys

The *ROSAT all-sky-survey* (RASS) has been made available in electronic form[23]. A catalogue of Abell-like clusters of galaxies selected from the RASS has been published[24]. Radio counterparts of many X-ray sources found in the RASS have been identified using the *Molonglo* 408 MHz survey and the *Green-Bank* 5 GHz survey[25–26].

From 254 *ROSAT* PSPC observations covering 40 deg^2, evidence is found[27] for the clustering of the faint X-ray sources on scales of $0'.5$-$10'$. The UK Deep/Medium Survey[28] finds 141 sources to $S_{0.5-2keV} = 3.2 \times 10^{-15}$ erg s^{-1} cm^{-2} in a ROSAT PSPC observation of a 0.9 deg^2 region, concluding that limits to the slope of the $\log N$–$\log S$ relation in this part of the spectrum are set by uncertainties in the measured X-ray background. A deep ROSAT PSPC survey[29] of a field near the SGP, which had been well observed in the optical, reveals a steep luminosity evolution with redshift for the X-ray luminosity function of QSOs (107 QSOs, $S_{0.5-2keV} > 4 \times 10^{-15}$ erg s^{-1} cm^{-2}).

5. Gamma-ray Surveys

The *BATSE* 2B catalogue, reporting 585 cosmic γ-ray bursts has been made available[30], and it has been used to derive a $\log N$-$\log S$ relation[31]. A cosmological origin of the bursts has been inferred from the observed isotropy of the first 1005 bursts[32] (see, however, ref. 33). At higher energies, the second *EGRET* catalogue, listing 129 GeV sources (including 11 AGN) has been published[34].

6. Optical Surveys

The very local luminosity function of galaxies is determined from the *Optical Redshift Survey*[35] sample of all galaxies with diameter $\geq 1'.9$ or blue magnitude ≤ 14.5. The distribution of galaxies seems to be remarkably inhomogeneous even on the largest scales probed by redshift surveys of optically selected galaxies. The *Las Campanas Redshift survey* covers a volume of $10^7\, h^{-3}$ Mpc^3 and finds excess power on scales of $\sim$100 Mpc[36].

To measure deviations from the Hubble flow, HI velocity widths of a volume-limited sample ($<40\, h^{-1}$ Mpc) of southern spirals have been measured[37] as part of a Tully-Fisher survey. Elsewhere, it has been shown that by optimizing the galaxy selection, the I-band Tully-Fisher relation can be used to measure their relative distances to 5% accuracy[38].

APM scans of UKST Sky-Survey plates have been used to generate two catalogues of bright ($m_{B_J} \leq 17$) galaxies: (a) the *APM Bright Galaxy catalogue*[39], containing over 14000 galaxies in a $\sim$4000 deg^2 area surrounding the SGP and (b) the *APM Equatorial catalogue*[40], containing over 30000 galaxies covering $\sim$5000 deg^2 in the region $-17^\circ.5 \leq \delta \leq 2^\circ.5$. These galaxies are identified and measured in a semi-automated way, and morphological classifications are assigned by eye. A similar automated star-galaxy separation algorithm has been used to find 79 clusters of galaxies (the *Palomar Distant Cluster Survey*[41], $0.2 < z < 1.2$) on CCD frames covering 5.1 deg^2. The density of $R \geq 1$ clusters in this catalogue is twice that in the Abell catalogue, indicating that the latter may be seriously incomplete.

The APM Sky-survey scans have also been used to compile a homogenous sample of 1055 bright ($16 \leq m_{B_J} \leq 18.5$) QSOs between $0.2 \leq z \leq 3.4$ (the *Large bright quasar survey*)[42]. On the other hand all QSOs with measured emission redshifts by the end of 1992 are represented in the revised and updated *Hewitt-Burbidge catalogue*[43].

Using the *CFHT* to obtain redshifts of a radio-selected *micro-Jansky* ($S_{5GHz} > 16\, \mu Jy$) population of radio sources, it has been inferred that a majority of such sources are related to AGN activity[44], which is unlike the *milli-Jansky* ($0.1 < S_{1.4GHz} < 1$ mJy) population to which starbursts are thought to be the main contributor[45]. A survey for optical variability of 180 optically selected quasars has provided evidence for the variability to increase with redshift for intrinsically bright ($-25 \leq M_B \leq -27$) quasars[46].

In order to constrain the theories of structure formation in the early universe and to address the prevailing uncertainty over the evolution of the QSO luminosity function at $z \geq 2$, a number of search programmes for distant QSOs, particularly those at $z \geq 4$, have been undertaken. The *Palomar Transit Grism Survey* has revealed[47–48] nine $z \geq 4$ QSOs in 61.5 deg^2 of the sky. Also, multi-colour selection techniques have been employed by different groups[49–50]. to discover QSO candidates with $z \geq 4$, many of which have been confirmed spectroscopically[51–52]. A conspicuous decline in the space density of QSOs between $z \sim$2–4 has been inferred in some of these studies. Assuming that elliptical galaxies belong to a homogenous population and their evolution is well understood, their I-band counts from a study of HST images seem not to favour the Λ-dominated cosmologies[53].

References

1. Soifer, B T (ed.), *"Sky Surveys: Protostars to Protogalaxies"*, ASP Conf. Ser., vol. 43, 1993.
2. Becker R H, White R L & Helfand D J 1995, ApJ, 450, 559
3. Cotton W D et al., 1996, in: *Extragalactic Radio Sources*, eds Ekers R.D. *et al.*, (Dordrecht: Kluwer), in press
4. de Bruyn G., 1996, in: *Extragalactic Radio Sources*, eds Ekers R D *et al.*, (Dordrecht: Kluwer), in press
5. Wright A E, Griffith M F, Burke B F & Ekers R D 1994, ApJS, 91, 111
6. Gregory P C, Vavasour J D, Scott W K & Condon J J 1994, ApJS, 90, 173
7. Kollgaard R I *et al.* 1994, ApJS, 93, 145
8. Lacy M, Riley J M, Waldram E M, McMahon R G & Warner P J 1995, MNRAS, 276, 614
9. Benn C R 1995, MNRAS, 272, 699
10. Hales S E G, Waldram E M, Rees N & Warner P J 1995, MNRAS, 274, 447
11. Kooiman B L, Burns J O & Klypin A A 1995, ApJ, 448, 500
12. Ciliegi P, Elvis M, Wilkes B J, Boyle B J, Mcmahon R G & Maccacaro T 1995, MNRAS, 277, 1463
13. Vermeulen R C & Cohen M H 1994, ApJ, 430, 467
14. Sanders D B, Egami E, Lipari S, Mirabel I F & Soifer B T 1995, AJ, 110, 1993
15. Mobasher B, Sharples R M & Ellis R S, 1993, MNRAS, 263, 560
16. Cowie L L, Gardner J P, Hu E M, Songaila A, Hodapp K-W & Wainscot R J, 1994, ApJ, 434, 114
17. Djorgovski G *et al.* 1995, ApJ, 438, L13
18. Glazebrook K, Ellis R, Colless M, Broadhurst T, Allington-Smith J & Tanvir N 1994, MNRAS, 273, 157
19. Gardner J P 1996, MNRAS, 279, 1157
20. Bowyer S *et al.* 1994, ApJS, 93, 569
21. Pye J P *et al.* 1995, MNRAS, 274, 1165
22. Bowyer S, Sasses T P, Wu X & Lampton M 1995, ApJS, 96, 461
23. Voges W *et al.* 1996, available from http://www.rosat.mpe-garching.mpg.de/survey
24. Ebeling H, Voges W, Bohringer H, Edge A C, Huchra J P & Briel U G 1996, MNRAS, 281, 799
25. Brinkmann W, Siebert J & Boller Th 1994, AA, 281, 355
26. Brinkmann W, Siebert J, Reich W, Fürst E, Reich P, Voges W, Trümper J & Wielebinski R 1995, AAS, 109, 147
27. Vikhlinin A & Forman W 1995, ApJ, 455, L109
28. Branduardi-Raymont G *et al.* 1994, MNRAS, 270, 947
29. Boyle B J, Shanks T, Georgantopoulos I, Stewart G C & Griffiths R E 1994, MNRAS, 271, 639
30. Meegan C A *et al.* 1994, available from grossc.gsfc.nasa.gov (Login:gronews)
31. Caditz D 1995, ApJ, 452, 140
32. Briggs M S *et al.* 1996, ApJ, 459, 40
33. Scharf C A, Jahoda K & Boldt E 1995, ApJ, 454, 573
34. Thompson D J *et al.* 1995, ApJS, 101, 259
35. Santiago B X, Strauss M A, Lahav O, Davis M, Dressler A & Huchra J P 1996, ApJ, 461, 38
36. Landy S D, Shectman S A, Lin H, Kirshner R P, Oemler A & Tucker D L 1996, ApJ, 456, L1
37. Roth J, Mould J & Staveley-Smith L 1994, AJ, 108, 851
38. Bernstein G M, Guhathakurta P, Raychaudhury S, Giovanelli R, Haynes M P, Herter T & Vogt N P 1994, AJ, 107, 1962
39. Loveday J 1996, MNRAS, 278, 1025
40. Raychaudhury S, Lynden-Bell D, Scharf C A & Hudson M 1994, BAAS, 26, 920
41. Postman M, Lubin L M, Gunn J E, Oke J B, Hoessel J G, Schneider D P & Christensen J A 1996, AJ, 111, 615
42. Hewett P C, Foltz C B & Chaffee F H 1995, AJ, 109, 1498
43. Hewitt A & Burbidge G 1993, ApJS, 87, 451
44. Hammer F, Crampton D, Lilly S J, Le Fevre O & Kenet T 1995, MNRAS, 276, 1085
45. Benn C R, Rowan-Robinson M, Mcmahon R G & Broadhurst T P 1993, MNRAS, 263, 98
46. Cristiani S, Trentin S, La Franca F, Arextaga I, Andreani P, Vio R & Gemmo A 1996, A&A, 306, 395
47. Schneider D P, Schmidt M & Gunn J E 1994, AJ, 107, 1245
48. Schmidt M, Schneider D P & Gunn J E 1995, AJ, 110, 68
49. Warren S J, Hewett P C & Osmer P S 1994, ApJ, 421, 412
50. Kennefick J D, Djorgovski S G & Meylan G 1996, AJ, 111, 1816
51. Smith J D *et al.* 1994, AJ, 108, 1147
52. Kennefick J D, Djorgovski S G & de Carvalho R R 1995, AJ, 110, 2553
53. Driver S P, Windhorst R A, Phillips S & Bristow PD 1996, ApJ, 461, 525

TESTS AND STATISTICS

J.A. PEACOCK

Royal Observatory,Blackford Hill, Edinburgh EH9 3HJ, UK

1. Geometry from the supernova Hubble diagram

The classical cosmological tests have fallen into disfavour in recent years – all attempts to measure the cosmological geometry with galaxies have fallen foul of unknown evolutionary corrections. This impasse may now be broken by using type Ia supernovae as the necessary standard candles. Riess, Press &

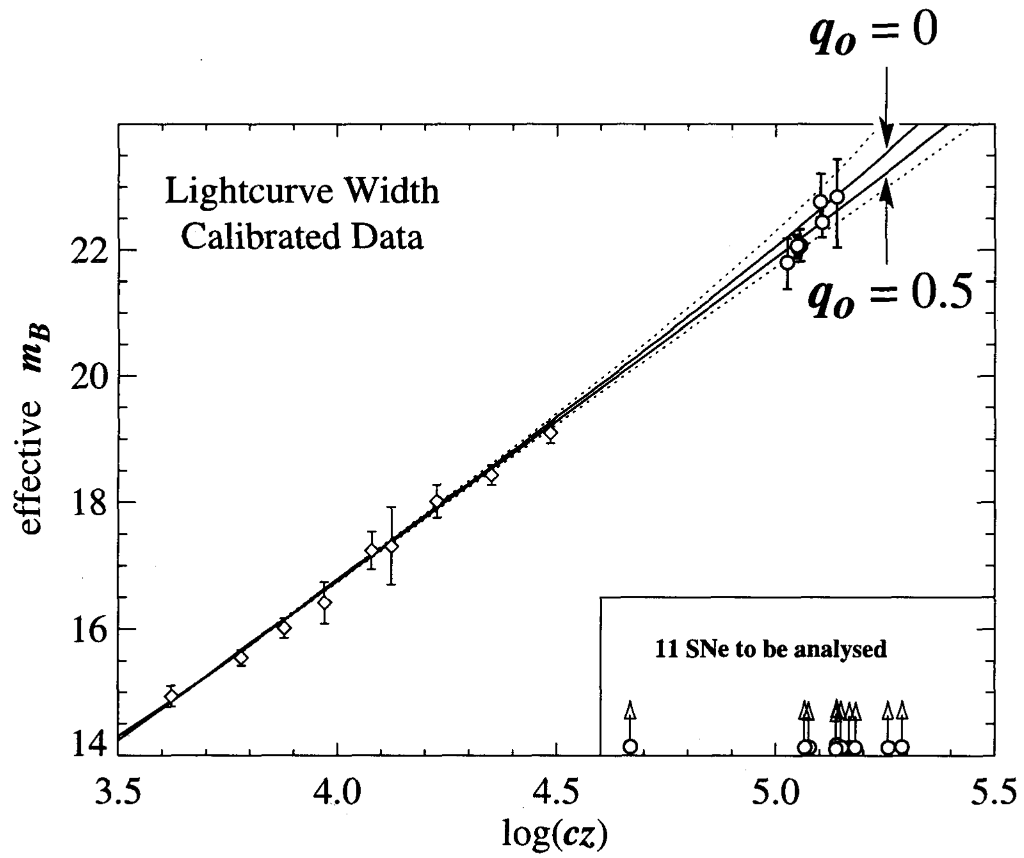

Figure 1. The type Ia supernova Hubble diagram, from Perlmutter et al. 1996. The apparent magnitude at maximum light has been corrected for light-curve shape. The deceleration parameter appears to be positive, and the upper dotted line ($q_0 = -1$) is clearly excluded. This places models with a dominant cosmological constant in some difficulty.

Kirshner (1995) found a correlation between peak brightness and the speed of the fall from maximum light, which allows relative distances between different supernovae to be inferred to an rms accuracy of 10%.

Several groups around the world are now reaching the point where they have accumulated data on a number of supernovae at $z \simeq 0.5$, and the first to report a preliminary determination of q_0 has been the US-UK-Australia-Sweden *Supernova cosmology project.* Their results to date are based on seven high-redshift type Ia supernovae, and their data are illustrated in figure 1 (Perlmutter et al. 1996). It appears that negative q_0 is firmly ruled out; the data favour values of a few tenths, consistent with an Einstein-de Sitter model, although not rejecting open models with $q_0 \simeq 0.1$. The significance of a decelerating universe is that it limits the size of the cosmological constant. Since $q_0 = \Omega_{\rm mass}/2 - \Omega_{\rm vac}$, $q_0 \simeq -0.7$ would be predicted for the inflationary low density models with $\Omega_{\rm mass} \simeq 0.2$ and $k = 0$.

Could this result be an artifact of evolution? The galaxies that host the supernovae may be younger, but the physical laws of stellar evolution must be the same. All that can change is the chemical composition of the progenitor stars, but this has a large dispersion today which seems not to affect the supernova brightness. This field is developing rapidly, and only one or two SNe at $z \simeq 1$ should give a high-precision measurement of q_0.

2. Galaxy evolution

The outstanding question in galaxy evolution has been the excess of faint galaxies, and what this tells us about the history of star formation in the universe. When data in blue wavebands only were available, it was possible to suggest that the cosmological model was in error; certainly the excess was greatly reduced when using models with larger high-redshift volume elements, such as those models dominated by a cosmological constant. This possibility was removed by the publication of the first galaxy luminosity function at 2μm (Glazebrook et al. 1995a). In this waveband, galaxies show little evolution between $z = 1$ and the present.

The blue excess appears to take the form of a population which is unimportant at the present day, but which dominates the blue data at $z \simeq 1$. This is shown clearly by major optical redshift surveys such as the CFRS (Lilly et al. 1995); Autofib (Ellis et al. 1996); Hawaii (Cowie et al. 1996). HST images show the expected counts of galaxies with normal morphologies, but with a rapidly-rising population of irregulars, which dominate at the faintest magnitudes (Glazebrook et al. 1995b). The unresolved question is where these galaxies have gone to today. They may be related to the steepening seen by some workers in the luminosity function at dwarf luminosities (Driver et al. 1994), or possibly to galaxies of low surface brightness, which are lost from local surveys (McGaugh 1994).

3. Quasars and AGN

Statistical work on the population of active galaxies continues to be dominated by 'unified models' of some form, in which different kinds of AGN are related by orientation-dependent effects (e.g. the review of Urry & Padovani 1995). While the evidence for obscured broad-line regions in many narrow-line AGN continues to mount, the debate continues over whether all narrow-line AGN host such objects. Some statistics, such as the relative sizes of radio galaxies and quasars, or the extended narrow-line regions of quasars, favour unification. Others, such as the total far-IR output, are more difficult to understand in this framework, which is in danger of becoming a paradigm.

Large quasar surveys have been built up, giving more precise optical luminosity functions (e.g. Hewett et al. 1993) and relations to the emission in different wavebands. Almost all the soft X-ray background is now resolved into AGN of varying sorts (Georgantopoulos et al. 1996). It has however been suggested (Webster et al. 1995) that quasar surveys are heavily incomplete, and that there is a large (possibly dominant) population of quasars which are so heavily reddened that they only appear in radio or infrared surveys. This claim is based on K-band detection of a large fraction of flat-spectrum radio sources which are optically invisible. However, although flat-spectrum radio sources are normally almost all quasars at bright radio fluxes, it is possible in this case that it is the host galaxy that is being detected; certainly the $R - K$ colours are consistent with this hypothesis.

An alternative means of detecting quasars is through their variability. This method is attractive in having no colour bias and no difficulty in distinguishing quasars from stars. Over a 15-year baseline, Hawkins (1996) claims to be able to recover all quasars found by traditional UVX techniques, as well as many redder objects. A controversial feature of this work is the quasar light curves, which are quite smooth, although the rms amplitude is high in most cases: several tenths of a magnitude. Hawkins points out that this behaviour is not predicted by intrinsic models and is consistent with microlensing by roughly a critical density of objects with $M \sim 10^{-3} M_\odot$. Accepting the nucleosynthesis limit to Ω_b, this implies either a universe of primordial black holes or some radical revision to models for intrinsic quasar variability.

References

1. Cowie L.L., Hu E.M., Songaila A., 1995, NAture, 377, 603
2. Driver S. et al., 1994, MNRAS, 268, 393
3. Ellis R.S., Colless M., Broadhurst T., Heyl J., Glazebrook K., 1996, MNRAS, 280, 235
4. Georgantopoulos I., Stewart G.C., Shanks T., Boyle B.J., Griffiths R.E., 1996, MNRAS, 280, 276
5. Glazebrook K., Peacock J. A., Miller L., Collins C., 1995a, MNRAS, 275, 169
6. Glazebrook K., Ellis R.S., Santiago B., Griffiths R., 1995b, MNRAS, 275, L19
7. Hawkins M.R.S., 1996, MNRAS, 278, 787
8. Hewett P.C, Folz C.B., Chaffee F.H., 1993, APj, 406, 43
9. Lilly S.J., Tresse L., Hammer F., Crampton D., Le Fèvre O., 1995, ApJ, 455, 108
10. McGaugh S.S., 1994, Nature, 367, 538
11. Perlmutter S., et al., astro-ph/9602122

12. Riess A., Press W., Kirshner R. 1995, ApJ, 438, L17
13. Urry C.M., Padovani P., 1995, PASP, 107, 803
14. Webster R.L., Francis P.J., Peterson B.A., Drinkwater M.J., Masci F.J., 1995, Nature, 375, 469

SOURCES AT HIGH z

P.A. SHAVER
European Southern Observatory - Karl-Schwarzschild-Str. 2,
85748 Garching, Germany

The highest-redshift objects known continue to be quasars, with redshifts up to 4.9, but radio galaxies and even normal galaxies have now also been found at high redshifts. Recent developments concerning quasars include new complete optically-selected samples which indicate a strong decline in apparent space density above $z \sim 2-3$ (Warren *et al.*, 1994; Schmidt *et al.*, 1995; Kennefick *et al.*, 1995, 1996; Hall *et al.*, 1996; Hawkins & Véron, 1996). Large, complete samples of radio-selected quasars prove that this decline is real, and not merely due to obscuration (Shaver et al., 1996). Most of the $z > 4$ quasars have been found using optical colour and spectroscopic techniques, but recently some have been found from their radio emission (Hook *et al.*, 1995; Shaver *et al.*, 1996), X-ray emission (Henry *et al.*, 1994), and variability (Hawkins *et al.*, 1996). Searches have been made for galaxies around the highest-redshift quasars (Soifer *et al.* 1994; Egami, 1995; Loeb & Eisenstein 1995; Lacy & Rawlings 1996).

Radio galaxies have now been found at redshifts as high as $z = 4.25$ (Lacy *et al.*, 1994), and there have been many studies of their properties and implications for the formation epoch of galaxies (*e.g.* Eales & Rawlings, 1993; Graham *et al.*, 1994; Spinrad *et al.* 1995; Mazzei & deZotti, 1996; Lacy & Rawlings, 1996; Dunlop *et al.*, 1996).

Searches for primeval or starbursting galaxies at high redshifts have continued, using a variety of techniques (Pritchet 1994; Thompson *et al.*, 1994, 1995; Thompson & Djorgovski, 1995; Pahre & Djorgovski, 1995; Malkan *et al.*, 1995; Bunker *et al.*, 1995; Mannucci & Beckwith, 1995; de Robertis & McCall, 1995). One such search was focused on $z > 7$ primeval galaxies (Parkes *et al.*, 1994).

A revolution has taken place over the last few years in the search for "normal" galaxies at high redshift, by using the Lyman break signature (Steidel & Hamilton, 1993; Giavalisco *et al.*, 1994; Steidel *et al.*, 1995, 1996; Madau, 1995; de Robertis & McCall 1995; Clements & Couch, 1996). Several galaxies have been found at $z > 3$, both around known quasars and in the field, with a space density similar to that of L^* galaxies today. A $z = 4.7$ object has been found within 3 arc sec. of a quasar at the same redshift (Fontana *et al.*, 1996; Hu *et al.*, 1996; Petitjean *et al.*, 1996). One study based on the Hubble Deep Field reports possible redshifts as high as 6 (Lanzetta *et al.*, 1996).

Other possibilities have been considered to find discrete objects at still higher redshifts. Mm/submm dust emission is present in high-redshift radio galaxies and quasars (Hughes *et al.* 1993; Chini & Krügel, 1994; Dunlop *et al.* 1994; Isaak *et al*, 1994; McMahon *et al.* 1994; Eales & Edmunds, 1996), and may provide a powerful search tool for young galaxies out to $z \sim 20$ (Franceschini *et al.*, 1994; Blain & Longair, 1996). Protoclusters might be detected at very high redshifts through their HI emission (Subramanian & Padmanabhan, 1993; Briggs *et al.*, 1993; Kumar *et al.*, 1995) or primordial molecular emission (Maoli *et al.*, 1994, 1996; Puy & Signore 1996; Stancil *et al.*, 1996).

References

1. Blain, A.W., Longair, M.S. 1996, MNRAS 279, 847
2. Briggs, F.H., Sorar, E., Taramopoulos, A. 1993, ApJ 415, L99
3. Bunker, A.J., Warren, S.J., Hewett, P.C., Clements, D.L. 1995 MNRAS 273, 513
4. Chini, R., Krügel, E. 1994, A&A 288, L33
5. Clements, D.L., Couch, W.J. 1996, MNRAS 280, L43
6. deRobertis, M.M., McCall, M.L. 1995 AJ 109, 1947
7. Dunlop, J.S., Hughes, D.H., Rawlings, S., Eales, S.A., Ward, M.J. 1994, Nature 370, 347
8. Dunlop, J., Peacock, J., Spinrad, H., Dey, A., Jimenez, R. *et al.* 1996, Nature 381, 581
9. Eales, S.A., Rawlings, S. 1993, ApJ 411, 67
10. Eales, S.A., Edmunds, M.G. 1996, MNRAS 280, 1167
11. Egami, E. 1995, in *Wide Field Spectroscopy and the Distant Universe* (ed. S.J. Maddox & A. Aragon-Salamanca; World Scientific), p. 380

12. Fontana, A., Cristiani S., d'Odorico S., Giallongo E., Savaglio S. 1996, MNRAS 279, L27
13. Franceschini, A., Mazzei, P., de Zotti, G., Danese, L. 1994 ApJ 427, 140
14. Giavalisco, M., Steidel, C.C., Szalay, A.S. 1994 ApJ 425, L5
15. Graham, J.R., Matthews, K., Soifer, B.T., Nelson, J.E. *et al.* 1994, ApJ 420, L5
16. Hall, B., Osmer, P.S., Green, R.F., Porter, A.C., Warren, S.J. 1996, ApJ 462, 614
17. Hawkins, M.R.S., Shaver, P.A., Clements, D., van der Werf, P. 1996, MNRAS 280, L1
18. Hawkins, M.R.S., Véron, P. 1996, MNRAS 281, 348
19. Henry, J.P., Gioia, I.M., Böhringer, H., Bower, R.G. *et al.* 1994, AJ 107, 1270
20. Hook,I., McMahon, R., Patnaik, A., Browne, I. *et al.* 1995, MNRAS 273, L63
21. Hu, E.M., McMahon, R.G., Egami, E. 1996, ApJ 459, L53
22. Hughes, D.H., Robson, E.I., Dunlop, J.S., Gear, W.K. 1993, MNRAS 263, 607
23. Isaak, K.G., McMahon, R.G., Hills, R.E., Withington, S. 1994, MNRAS 269, L28
24. Kennefick, J.D., Djorgovski, S.G., de Carvalho, R.R. 1995, AJ 110, 2553
25. Kennefick, J.D., Djorgovski, S.G., Meylan, G. 1996, AJ 111, 1816
26. Kumar, A., Padmanabhan, T., Subramanian, K. 1995, MNRAS 272, 544
27. Lacy, M., Miley, G., Rawlings, S., Saunders, R. *et al.* 1994, MNRAS 271, 504
28. Lacy, M., Rawlings, S. 1996, MNRAS 280, 888
29. Lanzetta, K.M., Yahil, A., Fernandez-Soto, A. 1996, Nature 381, 759
30. Loeb, L., Eisenstein, D.J. 1995 ApJ 448, 17
31. Madau, P. 1995 ApJ 441, 18
32. Malkan, M., Teplitz, H., McLean, I. 1995, ApJ 448, L5
33. Maoli, R., Melchiorri, F., Tosti, D. 1994, ApJ 425, 372
34. Maoli, R., Ferrucci, V., Melchiorri, F., Signore, M., Tosti, D. 1996, ApJ 457, 1
35. Mannucci, F., Beckwith, S.V.W. 1995, ApJ 442, 569
36. Mazzei, P., de Zotti, G. 1996, MNRAS 279, 535
37. McMahon, R., Omont, A., Bergeron, J., Kreysa, E., Haslam, C. 1994, MNRAS 267, L9
38. Pahre, M.A., Djorgovski, S.G. 1995, ApJ 449, L1
39. Parkes, I.M., Collins, C.A., Joseph, R.D. 1994, MNRAS 266, 983
40. Petitjean, P., Pecontal, E., Valls-Gabaud, D., Charlot, S. 1996, Nature 380, 411
41. Pritchet, C.J. 1994, PASP 106, 704
42. Puy, D., Signore, M. 1996 A&A 305, 371
43. Schmidt, M., Schneider, D.P., Gunn, J.E. 1995 AJ 110, 68
44. Shaver, P.A., Wall, J.V., Kellermann, K.I. 1996, MNRAS 278, L11
45. Shaver, P.A. Wall, J.V., Kellermann, K.I., Jackson, C.A., Hawkins, M.R. 1996 (see Shaver, P.A. 1995, Ann. N.Y. Acad. Sc. 759, p.87)
46. Soifer, B.T., Matthews, K., Djorgovski, S., Larkin, J. *et al.* 1994, ApJ 420, L1
47. Spinrad, H., Dey, A., Graham, J.R. 1995, ApJ 438, L51
48. Stancil, P.C., Lepp, S., Dalgarno, A. 1996, ApJ 458, 401
49. Steidel, C.C., Hamilton, D. 1993, AJ 105, 2017
50. Steidel, C.C., Pettini, M., Hamilton, D. 1995, AJ 110, 2519
51. Steidel, C., Giavalisco M., Pettini M., Dickinson M., Adelberger K. 1996, ApJ 462, L17
52. Subramanian, K., Padmanabhan, T 1993, MNRAS 265, 101
53. Thompson, D., Djorgovski, S.G. 1995, AJ 110, 982
54. Thompson, D., Djorgovski, S., Beckwith, S.V.W. 1994, AJ 107, 1
55. Thompson, D., Djorgovski, S., Tranger, J. 1995, AJ 110, 963
56. Warren, S.J., Hewett, P.C., Osmer, P.S. 1994, ApJ 421, 412

HST DETERMINATIONS OF HUBBLE'S CONSTANT

WENDY FREEDMAN
Carnegie Observatory, 813, Santa Barbara Street
Pasadena CA 91101, USA

Since the 1994 refurbishment mission, HST has been able to undertake one of its primary cosmological missions, the task of determining a value of the Hubble constant with both systematic and random errors reduced to the 10% level. A Key Project was designated to undertake this assignment, and several additional projects were successful in using HST to obtain additional observations with the same goal in view.

The Key Project Team on the Extragalactic Distance Scale has now measured Cepheid distances to 8 galaxies in a comprehensive program aimed at setting the zero points and establishing the dispersions for five of the most precise secondary distance indicators useful on a cosmological scale: the Tully-Fisher relation, the Surface Brightness Fluctuation Method, the Expanding Photosphere Method for Type II Supernovae and the peak brightness decline rate method for Type Ia Supernovae. Other distance determination methods (with a shorter range of application, such as the Planetary Nebula Luminosity

Function and the Globular Cluster Luminosity Function methods) are also being calibrated as a matter of course. The galaxies for which distances have been measured to date include M81, M101, M100, NGC 925, NGC 3351, NGC 3621, NGC 2090, and NGC 1365.

The first demonstration of the feasibility of the Key Project to accomplish its stated goals of determining Cepheid-based distances to more than 20 galaxies was the early discovery of Cepheids in the Virgo cluster galaxy M100 (Freedman *et al.*, 1994, Ferrarese *et al.* 1996). In total, more than 50 Cepheids with periods ranging from 10 to 60 days were found and measured in V and I bandpasses giving a reddening corrected true modulus for the host galaxy of 16.1 ± 1.5 Mpc. The Hubble constant determined both at Virgo and then tied to the cosmologically more distant Coma cluster leads to $H_0 = 80 \pm 16$ km/sec/Mpc. The uncertainty in this measurement will decrease as additional Virgo cluster distances are directly measured with HST.

Tanvir *et al.* (1995) successfully used HST to discover Cepheids in NGC 3333 (M95), a spiral galaxy in the Leo I Group, and used its distance to bootstrap out to the Coma cluster via Virgo. They determined a Hubble constant of 69 ± 8 km/sec/Mpc.

Sandage, Saha and their collaborators, in a series of papers designed to calibrate the zero point of the Type Ia supernova distance scale using Cepheid variables, have consistently found a lower value of the Hubble constant applying their calibration of SN in spiral and irregular galaxies to a more distant sample of SN in primarily elliptical host galaxies. In their most recent analysis (Sandage *et al.* 1996) based on an analysis of 7 type Ia supernovae, they find a value of $\mathrm{H}_0 = 57 \pm 7$ km/sec/Mpc.

In a new application of the tip of the red giant branch (TRGB) method of distance determination Sakai *et al.* (1996) used HST to measure a direct distance to the elliptical galaxy NGC 3379. This galaxy is a member of the Leo I group, whose distance was also measured by Cepheids discovered in M95 and NGC 3351, two members of the same group. The distances now determined independently by the Pop I Cepheid route and the Pop II RR Lyrae-based TRGB route agree to within 5%. The TRGB distance measurement to M96 has allowed the direct determination of the zero point of SBF, PNLF and the $\mathrm{D}_n - \sigma$ distance determination relation for elliptical galaxies. Application of each of these newly calibrated relations each result in values of the Hubble constant that are confined to the range 70 ± 8 km/sec/Mpc.

Most recently, the Key Project team has discovered a sample of 50 Cepheids in the Fornax galaxy, NGC 1365 (Madore *et al.* 1996, in preparation; Silbermann *et al.* 1996, in preparation). Based on the V and I PL relations, a reddening-corrected true distance modulus of 18.5 ± 0.9a Mpc is determined for this galaxy. The cluster provides a means of calibrating several secondary methods (the Tully-Fisher relation, type Ia supernovae, surface brightness fluctuations, and the planetary nebula luminosity function and globular cluster luminosity function).

References

1. Ferrarese, L. et. al. (1996) *Ap.J.*, **464**, 568.
2. Freedman, W. et. al. (1994) *Nature*, **371**, 757.
3. Sakai, S. et. al. (1996) *Ap.J.*, **461**, 713.
4. Sandage, A. et. al. (1996) *Ap.J. Lett.*, **460**, L15.
5. Tanvir, N.R. et. al. (1995) *Nature*, **377**, 27.

COSMIC MICROWAVE BACKGROUND RADIATION

DAVID WILKINSON
Joseph Henry Laboratories, Princeton University
Princeton, NJ 08544, USA

1. Introduction

From 1990 to the present the Cosmic Background Explorer (COBE) satellite has produced seminal results on the cosmic microwave background radiation (CMBR). The COBE/FIRAS experiment found [1] the CMBR spectrum to be remarkably close to that of a blackbody from $\lambda = 5$ to 0.5 mm. The COBE/DMR experiment [2] detected the long-sought anisotropy in the CMBR on scales larger than 10°. Both results agree with the predictions of the hot Big Bang cosmological model and the idea that primordial density fluctuations (order 10^{-5}) cause CMBR temperature anisotropy and form the seeds of large scale structure in the universe. Further analysis of the COBE data sets (see references below) has improved the accuracy of these initial reports, without changing their main findings.

This short review of CMBR research emphasizes progress since the last Commission 47 report. [3] A more detailed review (with figures) is available on the internet. [4]

2. Anisotropy

The initial COBE/DMR result was based on 1 year of data. The measured sky map had a signal-to-noise ratio of 1:1, so the detection required statistical analysis. A cluster of 7 papers based on 4 years of data [5] reports the final COBE/DMR results. (The COBE instruments were turned off in late 1993.) The main results can be summarized as follows. (1) At angular scales greater than 10° the CMBR is anisotropic, $\Delta T/T \approx 10^{-5}$. (2) The spectrum of the fluctuations has a spectral index of $n = 1.2 \pm 0.3$ which is consistent with the scale-invariant ($n = 1$) primordial spectrum predicted by inflation. The fluctuations are consistent with Gaussian statistics. (3) The quadrupole normalization is about 15 μK. While in agreement with standard Big Bang cosmology and inflation, none of these results are strong enough to verify this model. The 4-year COBE/DMR maps have a signal-to-noise ratio of about 2:1, and the CMBR anisotropy can be seen in these maps at high Galactic latitude.[5]

Post-COBE research on CMBR anisotropy has quickly turned to smaller angular scales. More than a dozen balloon-based [6] and ground-based [7] measurements have been reported since 1993. Most report detections of CMBR anisotropy at a level of a few $\times\ 10^{-5}$. This unusual activity was stimulated by advances in detector sensitivity (typically 100 times better than the COBE/DMR receivers) and by theoretical predictions of interesting features in the medium-scale power spectrum. [8] A series of peaks appears in the predicted angular power spectrum at angles between 1° and 0.2°. These peaks arise from acoustical oscillations during the decoupling process at $z \approx 1100$. The amplitude and position of these peaks reflect physical conditions at that time (age ≈ 300,000 yr) and thus offer an opportunity to measure interesting cosmic parameters at a known epoch in the early universe. Simulations of real and imagined experiments are playing an important role in experiment planning [9] — a process akin to the Monte Carlo simulations used to the design high energy physics detectors.

Rapid progress is being made on experiments to measure medium-scale CMBR anisotropy. Most new results indicate that the anisotropy at scales between 1° and 0.2° has an amplitude 2 or 3 times larger than the COBE/DMR anisotropy. This is expected from the theory of decoupling, but it is too soon to extract meaningful cosmological or physical parameters from these data. Error bars are still large and the effects of systematic errors and foreground sources are still being evaluated.

The high level of interest in medium-scale anisotropy is pushing the field ahead at an unusually rapid pace, for cosmology experiments. Better detectors, drier sites, longer balloon flights, and improved techniques (e.g. beam scanning instead of beam switching) are being developed. A very promising development is that several groups are building close-packed interferometers to map medium-scale and small-scale CMBR anisotropy. It is reasonable to expect that the predicted peaks will be seen or ruled out within the next 5 years. However, simulations show that (as with COBE) well-calibrated, full-sky maps are needed to make optimum use of the information carried by the CMBR anisotropy. Given the potential for accurate measurement of important cosmological constants, two satellites are planned for launch within the next decade. MAP is a NASA mid-sized explorer and COBRAS/SAMBA is a more ambitious ESA mission; both will be placed in solar orbit at the earth-sun L2 point to assure good isolation from the effects of earth and moon emission.

3. Spectrum

Measurements of the CMBR spectrum are a stringent test of the hot Big Bang cosmological model, because it makes a very strong prediction—relic microwave radiation with a strictly (to 1 part in 10^5) blackbody spectrum. The COBE/FIRAS data have now been analyzed with great care taken to account for tiny instrumental effects and calibration errors.[10] The results[11] based on analysis of part of the FIRAS data set showed that deviations of the CMBR spectrum from a blackbody are less than 0.03% of the peak intensity. This analysis gave a CMBR temperature of 2.726 ± 0.010 K. The most recent paper [12] from this group reports that deviations from a blackbody are less than 0.005% and that the CMBR temperature is 2.728 ± 0.004 K. The small limits on deviations from a blackbody spectrum are strong constraints on viable cosmological models.

The good fit to a blackbody also constrains models for heating the matter or radiation after $z \approx 10^7$. After this time thermal equilibrium cannot be re-established by radiative processes. Depending on when the heating occurs, the distortion is characterized by μ (Bose-Einstein), y (Compton), or free-free emission at long wavelengths. The latest COBE/FIRAS results give $\mu < 9\times 10^{-5}$ and $y < 1.5\times 10^{-5}$.

The COBE/FIRAS instrument measured the CMBR from $\lambda = 5$ to 0.5 mm. The space environment allowed accuracy and wavelength coverage not available from the ground. However, some possible distortions of the CMBR spectrum could be largest at longer wavelengths. Galactic foreground emission, atmospheric emission, and ground radiation into antenna side-lobes hamper such measurements.[13] At wavelengths shorter than about 10 cm, balloons can be used to make measurements of < 1% accuracy.[14]

4. Polarization

Polarization of the CMBR has been predicted for a long time.[15] However, the expected magnitude is only about 10% of the temperature anisotropy, and experiments are only now achieving the needed sensitivity. Recent reviews[16] [17] discuss the current theoretical and experimental situation. CMBR polarization is particularly sensitive to scenarios that deviate from the standard Big Bang model with cold dark matter. For, example, topological defects,[18] tensor modes,[17] and early re-ionization ($z > 20$)[19] leave distinct signatures in the CMBR polarization.

References

1. Mather, J.C., *et al.* 1990, ApJ 354, L37.
2. Smoot, G.F., *et al.* 1992, ApJ 396, L1.
3. Smoot, G.F. & Mather, J.C. 1993, Reports on Astronomy, Vol. XXIIA, ed. Bergeron, J., p554. Vittorio, N.,*ibid.* p558.
4. Smoot, G.F. & Scott, D. 1996, astro-ph/6903157.
5. Bennett, C.L., *et al.* 1996, ApJ 464, L1. Kogut, A., *et al.*, *ibid.*, L5. Gorski, K.M., *et al.*, *ibid.*, L11. Hinshaw, G., *et al.*, *ibid.*, L17. Wright, E.L., *et al.*, *ibid.*, L21. Hinshaw, G., *et al.*, *ibid.*, L25. Kogut, A., *et al.*, *ibid.*, L29.
6. Ganga, K., *et al.* 1993, ApJ 432, L15. de Bernardis, P., *et al.* 1994 ApJ 422, L33. Tanaka, S.T., *et al.* 1996, ApJ in press, astro-ph/9512067. Cheng, E.S., *et al.* 1996, ApJ 456, L71.
7. Subrahmayan, R. *et al.* 1993, MNRAS 263, 416. Hancock, S., *et al.*, 1994, Nature 367, 333. Gundersen, J.O., *et al.* 1994, ApJ 443, L57. Wollack, E.J., *et al.* 1993, ApJ 419, L49. Netterfield, C.B., *et al.* 1995, ApJ 445, L69; 1996, astro-ph/9601197. Ruhl, J., *et al.* 1995, ApJ 453, L1. Scott, P.F.S., *et al.* 1996, ApJ in press. Tucker, G.S., *et al.* 1993, ApJ 419, L45.
8. Peebles, P.J.E. & Yu, J.T. 1970, ApJ 162, 815. Bond, J.R. & Efstathiou, G. 1987, MNRAS 226, 655. For a complete list of recent references see: Hu, W. & White, M. 1996, astro-ph/9602019.
9. Jungman, G., *et al.* 1996, Phys.Rev. D54, 1332. Knox, L. 1996, astro-phy/9606066. Kosowsky, A., *et al.* 1996, Proc. UCLA Dark Matter Conf., astro-ph/9605147.
10. Fixsen, D.J., *et al.* 1994, ApJ 420, 457.
11. Mather, J.C., *et al.* 1994, 420, 439.
12. Fixsen, D.J., *et al.* 1996, ApJ, in press; astro-ph/9604158.
13. Staggs, S.T., *et al.* 1996, ApJ 458, 407.
14. Staggs, S.T., *et al.* 1996, ApJ Let., in press.
15. Rees, M.J. 1968, ApJ 153, L1.
16. Kosowsky, A. 1996, Annals of Physics 246, 49.
17. Seljak, U. 1996, astro-ph/9608131.
18. Coulson, D., Crittenden, R.G. & Turok, N. 1994, Phys Rev Lett 73, 2390.
19. Crittenden, R., Davis, R. & Steinhardt, P. 1993, ApJ 417, L13.

RAIDATION BACKGROUND AT OTHER WAVELENGTHS

AJIT K. KEMBHAVI
Inter-University Centre for Astronomy and Astrophysics
Post Bag 4, Ganeshkhind, Pune - 411 007

Diffuse radiation attributable to extragalactic sources has been observed in different regions of the electromagnetic spectrum. We will review in this section some recent literature on the subject, omitting from consideration microwave background radiation, as this will be dealt with by another contributor (D.T. Wilkinson) in this review.

The X-ray Background: The X-ray background (XRB) was the first diffuse radiation to be discovered in the sky. The XRB above 0.25 keV is dominated by contribution from extragalactic sources and is isotropic to within a few percent on large scales. The spectrum of the XRB is a power-law from 0.5 to 3 keV, thereafter has the thermal bremsstrahlung form with $T \sim 40\,\mathrm{keV}$ until $\sim 60\,\mathrm{keV}$, and can be represented as a sum of two steep power-laws at higher energies until 6 MeV. Initial results from the Japanese satellite *Asca* (Gendreau et al. (1995)) have shown that the XRB can be represented by a single power-law between 1 and 10 keV and that there is a clear excess above this power-law below 1 keV. It is believed that much of the XRB is due to contribution of discrete sources of different kinds, but the outstanding difficulty here is that the known spectra of plausible contributing sources do not match the spectrum of the X RB (see Fabian & Barcons 1992 for a review). Over the last few years there has been much progress in estimating the discrete source contributions, primarily because of data from the X-ray astronomy satellite *ROSAT*.

The contribution of discrete sources can be directly assessed through (1) direct surveys in which discrete sources are counted, (2) analysis of fluctuations in the background intensity from field to field, which provides information about sources below t he detection threshold, (3) cross correlation of the fluctuations with catalogues of sources at other wavelengths and (4) analysis of the autocorrelation of the XRB. A more indirect approach is to use the known luminosity function (space density) of different species of sources in some band, together with the distribution of ratio of X-ray luminosity to the luminosity in that band to assess the discrete source contribution. The direct approaches are useful in assessing the overall contribution of the discrete sources, while the latter is more useful in determining the contribution of a given kind of source, say quasars.

A very deep survey (exposure $\sim 150\,\mathrm{ksec}$) of an area of the sky known to have the lowest absorbing column density has been carried out by Hasinger et al. (1993) with the Position Sensitive Proportional Counter on *ROSAT*. They find that $\sim 60\%$ of the XRB at 1 keV is resolved, i. e., is due to discrete sources brighter than $\sim 2.5\times10^{-15}\,\mathrm{erg\,cm^{-2}\,sec^{-1}}$ in the $0.5-2\,\mathrm{keV}$ range. Further, on the basis of a fluctuation analysis, Hasinger et al. have set an upper limit of $\sim 25\%$ on the contribution of a truly diffuse component to the XRB. *ROSAT/PSPC* fields have also been analysed for fluctuations by Georgantopoulos et al. (1993), Barcons et al. (1994), who find a discrete source contribution of 70% above a flux level of $7\times10^{-16}\,\mathrm{erg\,cm^{-2}\,sec^{-1}}$, which means that the source count has to steepen below this limit, or there must be some other source for the residual XRB, and Branduardi-Raymont et al. (1994).

Using cross-correlations between X-ray fluctuations in deep *ROSAT* fields with galaxy catalogues, Lahav et al. (1993) and Roche et al. (1995) have found that galaxies with magnitude $B < 23$ can contribute $\sim 17\%$ of the XRB, while Treyer et al. (1996) find that faint blue galaxies contribute $\sim 22\%$. Carrera et al. (1995) have used cross-correlations of *GINGA* X-ray data and galaxy catalogues to show that $10-30\%$ of the XRB in the $2-10\,\mathrm{keV}$ range is produced by galaxies. The autocorrelation technique has been used on PSPC fields by Chen et al. (1994) to show that sources contributing to the XRB must have a correlation length $< 4h_{50}^{-1}$ Mpc and by Soltan & Hasinger (1994) and Soltan et al. (1996) to show that QSOs contribute $< 35\%$ of the XRB.

From their X-ray luminosity function the contribution of QSOs to the $(1-2\,\mathrm{keV})$ XRB has been assessed to be $34-53\%$ by Boyle et al. (1994), while Georgantopoulos et al. (1996) have shown that AGN contribute $< 45\%$. The ability of Seyfert 1 and 2 galaxies and QSOs to produce the XRB with the correct spectrum at energies greater than a few keV has been considered, amongst others, by Zdziarski et al. (1993), Madau et al. (1994), Matt & Fabian (1994), Comistri et al. (1995), Vikhilin (1995) and Zdzdiarski et al. (1995).

The γ−ray Background: A diffuse, isotropic and therefore presumably extragalactic γ−ray background has been known to exist since SAS-2 observations (Fichtel et al. 1978), and preliminary results are available from the *Egret* experiment on the *Compton Gamma Ray Observatory* (CGRO). Stecker & Salamon (1996) have shown that γ − ray emission from blazars, which have been observed with the CGRO, can account for the whole of this background. This is consistent with the results of Setti & Woltjer (1994) who also find that normal galaxies contribute $< 10\%$, and of Chen et al. (1996). Dar & Shaviv (1995) have argued that the background could be produced by the interactions of high energy cosmic rays in clusters of galaxies if they have intensity comparable to that in our Galaxy.

Other Backgrounds: Armand et al. (1994) have used galaxy counts at 2000Å to show that the integrated light of galaxies brighter than 18.5m is comparable to the far ultra-violet (UV) diffuse background. Vogel and Reimes (1993) have used HST spectroscopic observations of two quasars to constrain the shape of the UV background to a power-law with index in the range (0.5, 0.1). Overduin and Wesson (1993) have used the observed UV background to place upper limits on the mass of axions which are assumed to be clustered in galactic halos and decay into photon pairs, contributing to the UV background. Dodelson & Jubas (1994) have also constrained decaying particle mass in a similar manner and commented that a distinct signature of decaying dark matter is a sharp drop in the Infra-red spectrum. Biller et al. (1995) have derived an upper bound on the energy density of infra-red background radiation from the effects of photon-photon interactions on the observed TeV spectrum of the active galaxy Mkn 421. Puget et al. (1996) have reported the tentative detection of a far-infrared background ($400-1000\,\mu$m) from the COBE whole sky survey, which could be the predicted background from early galaxies (see e.g. Franceschini et al. 1994).

References

1. Armand, C. et al. (1994), *Astron. Ap.* **284**, 12.
2. Barcons, X. et al. (1994) *MNRAS* **268**, 833.
3. Biller S. D. et al. (1995) *ApJ* **445**, 227.
4. Boyle, B. et al. (1994) *MNRAS* **271**, 639.
5. Branduardi-Raymont, G. et al. (1994) *MNRAS* **270**, 947.
6. Carrera, F. G. et al. (1995) *MNRAS* **275**, 22.
7. Celotti, A. et al. (1995) *MNRAS* **277**, 1169.
8. Chen L.-W. et al. (1994) *MNRAS* **266**, 846.
9. Chen, A. et al. (1996) *ApJ* **463**, 169.
10. Comistri, A. et al. (1995) *Astron. Ap.* **296**, 1.
11. Dar, A. & Shaviv N. J. (1995) *Phys. Rev. Lett.* **75**, 3052.
12. Dodelson, S. & Jubas J. M. (1994) *MNRAS* **266**, 886.
13. Fabian, A. C. & Barcons, X. (1992) —it Ann. Rev. Astron. Ap. **30**, 429.
14. Fichtel, C. E. et al. (1978) *ApJ* **222**, 833.
15. Gendreau et al. (1995) *PASJ* **47**, 15.
16. Georgantopoulos I. et al. (1993) *MNRAS* **262**, 619.
17. Georgantopoulos I. et al. (1996) *MNRAS* **280**, 276.
18. Hasinger, G. et al. (1993) *Astron. Ap.* **275**, 1.
19. Lahav, o. et al. (1993) *Nature* **364**, 693.
20. Matt, G. & Fabian, A.C. (1994) *MNRAS* **267**, 94.
21. Madau, P. et al. (1994) *MNRAS* **270**, L17.
22. Overduin, J. M.. & Wesson, P. S. (1993) *ApJ* **414**, 449.
23. Puget, J.-L. et al. (1996) *Astron. Ap. 308*, L5.
24. Roche, N. et al. (1995) *MNRAS* **273**, L15.
25. Soltan, A.& Hasinger, G. (1994) *Astron. Ap. 288*, 77.
26. Soltan, A.et al. (1996) *Astron. Ap. 305*, 17.
27. Setti, G & Woltjer, L. (1994) *ApJS* **92**, 629.
28. Stecker, F. W. & Salamon, M. H. (1996) *ApJ* **464**, 523.
29. Treyer, M. A. and Lahav, O. (1996) *MNRAS* **280**, 469.
30. Vikhilin, A. (1995) *Astron. Ap.* **303**, 714.
31. Vedel H. et al. (1994) *MNRAS* **271**, 743.
32. Vogel, S. & Reimers, D. (1993) *Astron. Ap.* **274**, L5.
33. Zdziarski, A. A. et al. (1993) *ApJ* **414**, L81.
34. Zdziarski, A. A. et al. (1995) *ApJ* **438**, L63.

INFLATION AND OTHER THEORETICAL MODELS

T. PADMANABHAN
Inter-University Centre for Astronomy and Astrophysics
Post Bag 4, Ganeshkhind, Pune - 411 007

The concept of inflationary universe was introduced in early eighties by different authors (see Kazanas, 1980; Guth, 1981 and Sato, 1981) as a possible "solution" to certain "problems". During the early years, inflation acquired a religious status with its adherents calling its occurrence inevitable and its predictions unique. It was soon clear that the key role of inflation is not so much in "solving" some (possibly nonexistent) problems but in providing the initial density perturbations from which structures can grow. Most of the work in the last 3 years was heavily linked to the models for structure formation and the detection of CMBR anisotropy and possibly these are the areas in which inflation will continue to exert influence (see, for a review, Liddle and Lyth, 1993).

The original models for the inflation made the following two "generic" predictions. (i) The present day universe will have $\Omega = 1$ (ii) The spectrum of initial perturbations has the form $P(k) = Ak^n$

with $n \approx 1$; the value of A is model dependent. Given such an initial condition and the nature of the nonbaryonic component [cold dark matter, hot dark matter, cosmological constant or some combination of the above], it is possible to evolve the perturbations to the present epoch and compare the results with observations. Such an exercise - carried out by several people - shows that the results are disappointing. To begin with, there does not seem to exist any reasonable model accommodating the two "generic" predictions of inflation and just *one* component for nonbaryonic energy density. Even when more than one component is invoked, the available region of the parameter space is very small (Bagla et al., 1996). Finally, in any of these "viable" models, it is necessary to fine-tune the values of dimensionless constants to an extraordinary degree in order to make the models work. For example, the so called "best-fit model" (Turner, 1991; Krauss and Turner, 1995) using a cosmological constant *and* CDM requires an extreme fine tuning of both the amplitude of initial perturbations and the value of the cosmological constant.

These realisations have led the inflationists to backtrack on the original claims of "uniqueness" of predictions and look for models which are merely not in contradiction with the observations. To begin with, it is possible to come up with inflationary models (Ratra and Peebles, 1994; Bucher et al., 1995; Kamionkowski and Spergel, 1994) which do *not* lead to $\Omega = 1$. This implies, among other things, that a definitive observational evidence for $\Omega \neq 1$ will not refute inflation, making the concept of inflation more difficult to test. Secondly, it is possible to have inflationary models which can produce initial spectra with $n \neq 1$, if it is needed. In fact, it is possible to construct an inflationary potential so as to reproduce the given spectra (Copeland et al, 1993; Mielke and Schunk, 1995; Turner and White, 1996). [This exercise was partially triggered by the analysis of second year COBE data which suggested that $n \neq 1$; with a more recent analysis of the data, the fashion might change again]. Thus, in some sense, inflationary models have lost their predictive power. The currently popular approach is to use the anisotropies of the CMBR and other observations (like the age of the universe, value of the Hubble constant etc.) to put constraints on Ω and the primordial spectrum. It is then possible to construct an inflationary model which will reproduce the observed values of various cosmological parameters. Inflationists would still claim that this is a positive approach and, in fact, observations are now used to probe, say, the physics at 10^{14} GeV. It is doubtful whether an average astronomer or cosmologist will consider such a procedure useful in any way.

One reason for inflationary models to survive for such a long time in different incarnations is the following: No other model for the production of initial perturbations works any better. The leading contenders to the inflationary model were the ones based on "seeds" in the early universe (see Brandenberger, 1994 for a review). Cosmic strings and textures have been two of the many cosmic defects which were invoked as possible seeds. These models have not gained any major popularity during the period under review. (see, for example, Perivolaropoulos and Vachaspati, 1994; Allen et al., 1994; Hindmarsh and Kibble, 1995) In particular, it is not quite clear whether seeded models can reproduce correctly the power spectra of perturbations in the present day universe.

References

1. Allen, B., Caldwell, R.R., Shellard, E.P.S., Stebbins, A. & Veeraraghavan, S., (1994), in *CMB Anisotropies Two years After COBE*, ed. L.M. Krauss, World Scientific, Singapore, p. 166.
2. Bagla, J.S., Padmanabhan, T., and Narlikar, J.V., (1996), *Comm. on Astrophys.*, **18**, 275
3. Brandenberger, R., (1994), *Int. J. Mod. Phys.* **A9**, 2117.
4. Bucher, M., Goldhaber, C.S. and Turok, N., (1995) *Nuc. Phys B S43*, 173
5. Copeland, E.J., Kolb, E.W., Liddle, A.R. and Lidsey, J.E., (1993), *Phys. Rev. Letts* **71**, 219; *Phys. Rev. D.* **48**, 2529
6. Guth, A.H., (1981), *Phys. Rev.*, **D23**, 347
7. Hindmarsh, M. &Kibble, T., (1995), *Rep. Prog. Phys.*, **58**, 477
8. Kamionkowski, M and Spergel, D.N., (1994),*Ap. J.* **432**, 7
9. Kazanas, D., (1980), *Ap.J.*, **241**. L59
10. Krauss, L. and Turner, M.S., (1995) *preprint*, astro-ph/9504003
11. Liddle, A.R. and Lyth, D.H. (1993), *Phys. Repts*, **231**, 1 (section 5)
12. Mielke, E.W. and Schunck, F.E. (1995), *Phys. Rev. D.*, **52**, 672
13. Sato, K., (1981), *MNRAS*, **195**, 467
14. Perivolaropoulos, L. & Vachaspati, T. (1994), *Ap.J* **423**, L77
15. Ratra, B. and Peebles P.J.E. (1994) *Ap. J.***432**, L5
16. Turner, M.S., (1991), *Phys. Scripta*, **T 36**, 167
17. Turner, M.S., (1993), *Phys. Rev. D.*, **48**, 3502; ibid **48** 5539.
18. Turner, M.S. and White, M., (1996), *Phys. Rev. D.*, **53**, 6822

RELICS OF THE BIG BANG : RECENT DEVELOPMENTS

KANDASWAMY SUBRAMANIAN
NCRA-TIFR, Poona University Campus, Pune 411007, India.

The two most important relics of the big bang, are the cosmic background radiation (CBR) and the abundance of light elements. We briefly review below recent developments regarding the light element abundances, concentrating on the recent possible detections of deuterium at high redshift[1,2,3]. A more complete review of big bang nucleosynthesis (BBN) can be found in ref 4. The recent work on the CBR is being separately reviewed by D. Wilkinson in this report.

Nuclear reactions a few seconds after the big bang, are supposed to produce the light isotopes - deuterium (D), ^{3}He, ^{4}He, ^{7}Li. A measurement of primeval light element abundances is crucial, for both checking the self consistency of BBN and also for determining the baryon density in the universe. One of the early successful predictions of BBN was that the abundance (Y) of ^{4}He is about 24% by mass. Since stars are net producers of ^{4}He, astronomers go to metal poor regions to determine its abundance[5]. An analysis of very metal poor ionised, extragalactic gas clouds, yields[6] $Y = 0.232 \pm 0.003 \pm 0.005$, where the errors refer to statistical and systematic ones respectively. This is consistent with BBN predictions for a range of baryon densities about the value 2×10^{-31} gm cm^{-3}. The value of Y, however, varies only logarithmically with the baryon density and so does not strongly constrain it. The deuterium abundance, on the other hand, is a rapidly decreasing function of the baryon density. Also its later evolution is relatively simple- stars only destroy it. A determination of the primeval deuterium abundance is therefore very important.

Attempts to measure a truly primeval deuterium abundance has concentrated on searching for the deuterium Lyman-α absorption line in the spectra of high redshift quasars. This occurs about 82 km s^{-1} bluewards of the corresponding hydrogen line. One needs to look in the vicinity of a high enough H column density line, since one expects a ratio D/H $\sim 10^{-4} - 10^{-5}$. But the velocity width of the H line must be low enough that it does not swamp the deuterium feature. Needless to say, one requires spectra with very high spectral resolution ($\sim$ 10km s^{-1}) and signal to noise. In addition, there also exists the additional complication that that a given line, even if it appears where the deuterium feature is expected, may be a chance hydrogen interloper. The most exciting recent development in this context has been the possible detection of deuterium in several high redshift absorption line systems[1,2,3].

Tytler et al[3] looked at the high redshift quasar 1937 - 1009 (z = 3.78), with the high spectral resolution spectrograph on the Keck 10-m telescope. They detected strong absorption at the expected position of the D Lyα line ($z_{abs} = 3.57$) and estimated from their work a D/H ratio of about 2.3×10^{-5}. This corresponds to a baryon density of about 4.4×10^{-31} g cm^{-3} or an $\Omega_b \sim 0.024h^{-2}$. However the detections of the D line ($z_{abs} = 3.32$), by the other two groups[1,2], looking at the quasar Q0014+813, imply a much higher D/H ratio of 2×10^{-4} and so a much lower baryon density 1.3×10^{-31} g cm^{-3}. The arguments for and against these two values are well summarised by Schramm and Turner[7].

Note that any detection is conservatively looked at as an upper limit, because of the possibility of chance interlopers. One way to reconcile the above observations is to say that the low value of D/H is the true value and the high abundance measurement may be due to a chance hydrogen interloper. But Rugers and Hogan[8], argue that the D line is too narrow to be due to a hydrogen interloper. Also relevant in this context are the recent measurements of D/H in the local interstellar medium[9], using the HST, which give a value of 1.6×10^{-5}. A high primeval D/H of 2×10^{-4} then implies that more than 90% of the material in the local interstellar medium has been through stars at least once. This appears inconsistent with many standard models of galactic chemical evolution[10]. Further detections are needed to clarify these issues but clearly, despite the controversy, these first detections of high redshift deuterium represent important progress.

References

1. Songaila, A. et al., 1994, Nature, 368, 599.
2. Carswell, R. F. et al., 1994, MNRAS, 268 L1.
3. Tytler, D., Fan, X-M & Burles, S. 1996, Nature, 381, 207.
4. Copi, C. J., Schramm, D. N. & Turner, M. S. 1995, Science, 267, 192.
5. Pagel, B. E. J. et al. 1992, MNRAS, 255, 325.
6. Olive, K. A. & Steigman, G. 1995, ApJ Suppl., 97, 49.
7. Schramm, D. N. & Turner, M. S. 1996, Nature, 381, 193.
8. Rugers, M. & Hogan, C. J. 1996, ApJ, 459, L1.
9. Linsky, J. L. et al. 1995, ApJ, 451, 335.
10. Edmunds, M. G. 1994, MNRAS, 270, L37.

THE INTERGALACTIC MEDIUM

L.L. COWIE
Institute for Astronomy, University of Hawaii,
2680 Woodlawn Drive, Honolulu, HI 96822, USA

1. Introduction

As a result of improved spectrographs and detectors as well as the new capabilities arising from HST and the advent of the 10m class telescopes, there has been rapid progress in our direct observational knowledge of the IGM through quasar absorption line studies conducted during the reporting period. Amongst the most notable results was the mapping of the high column density ($N(H\,\textsc{i})=10^{21}$ cm^{-2}) damped Lyman alpha systems (DLAs) over the redshift interval $z = 0 \rightarrow 5$, which showed that the baryon density in this component peaked at values similar to that of the local galaxy population at a redshift of $z = 2 - 3$ and fell rapidly thereafter [28]. Studies of the metallicities in the DLAs show typical values near 1 percent of solar beyond $z = 2$, but rising values below this redshift [22, 21, 16, 30]. Small amounts of dust and deviations from cosmic abundances similar to those in halo stars may be present at the earlier redshifts. These lines of evidence are suggestive of a conversion of the intergalactic gas to galaxies which peaked after $z = 2$ [20].

Studies of lower column density systems in the Lyman alpha 'forest' show the remarkable result that similar (one percent) metallicities are also present in much lower column density systems down to $N(H\,\textsc{i})=10^{15}$ cm^{-2} [3, 29, 25] at $z = 2 - 4$. [25] also suggest that, as in the damped Lyman alpha systems and in the halo stars, alpha process elements may be enhanced relative to Fe process elements in this gas. It is not yet clear where this metallicity arises. It may arise from star formation in the the outer regions of forming galaxies or it could be a relic from earlier star formation at higher redshift.

A second dramatic result during the reporting period was the discovery of a He^+ absorption edge in the spectra of several quasars at $z \sim 3$ [13, 6]. While this was initially interpreted as a Gunn-Peterson effect, it now appears, with the discovery that the hydrogen Lyman alpha forest extends smoothly to column densities near 10^{12} cm^{-2} [12], that the He^+ opacity can arise in the forest [18, 17, 26]. Indeed, the numerical simulations discussed below suggest that there may be no smooth IGM at these redshifts [23]. The models also suggest that some of the lowest column density forest clouds may even arise in underdense regions of the IGM. The He^+ opacity appears to drop quite rapidly from a value greater than 1.7 at $z = 3.286$ [13] to a value of 1 at $z = 2.743$ [6]. A parallel drop in the ratio of Si IV/C IV over this redshift range [25] may indicate that this is caused by an evolution in the ionizing field.

Size measurements of the forest clouds using separated quasar lines of sight have given cloud radii in the range of $200 - 500$ h^{-1} kpc [7, 5, 8], though this is subject to assumptions about the geometry. In velocity space weak correlations have been found over 300 km s^{-1} in the Lyman alpha population [4] with a stronger correlation over the same velocity range in the C IV [9]. Locally there is still considerable debate over what fraction of the Lyman alpha absorbers are associated with galaxies. There has been some success in finding Lyman alpha absorbers from the extended halos of $z \gtrsim 0.1$ galaxies [15]. However, at least some Lyman alpha lines arise in galaxy voids [27, 24]. These authors suggest that low equivalent width systems may be less associated with galaxies and may lie instead in large-scale filamentary structures.

The evolution in the observations has been matched by rapid progress in numerical modeling of structure formation, which can make detailed predictions on structure and its evolution in various scenarios and cosmologies [2, 31, 1] These simulations are probing the lower column density forest, while tree-SPH simulations are also pushing to study the properties of damped Lyman alpha systems and Lyman limit systems in CDM scenarios [14]. The models are also now extending their scope to include the metal lines and these diagnostics may be expected to provide extremely rigorous tests of the evolution of the structure and of the metagalactic ionizing field [10].

References

1. Bond, J. R., Kofman, L., and Pogosyan, D. (1996) *Nature* **380**, 603–605.
2. Cen, R., Miralda-Escudé, J., Ostriker, J. P., and Rauch, M. (1994) *Astrophys. J.* **437**, L9–L12.
3. Cowie, L. L., Songaila, A., Kim, T.-S., and Hu, E. M. (1995) *Astr. J.* **109**, 1522–1530.
4. Cristiani, S., D'Odorico, S., Fontana, A., Giallongo, E., and Savaglio, S. (1995) *Mon. Not. R. astr. Soc.* **273**, 1016–1032.
5. Crotts, A. P. S., Bechtold, J., Fang, Y., and Duncan, R. C. (1994) *Astrophys. J.* **437**, L79–L82.
6. Davidsen, A. F., Kriss, G. A., and Zheng, W. (1996) *Nature* **380**, 47–49.

7. Dinshaw, N., Impey, C. D., Foltz, C. B., Weymann, R. J., and Chaffee, F. H. (1994) *Astrophys. J.* **437**, L87–L90.
8. Fang, Y., Duncan, R. C., Crotts, A. P. S., and Bechtold, J. (1996) *Astrophys. J.* **462**, 77–88.
9. Fernández-Soto, A., Lanzetta, K. M., Barcons, X., Carswell, R. F., Webb, J. K., and Yahil, A. (1996) *Astrophys. J.* **460**, L85–L88.
10. Haehnelt, M. G., Steinmetz, M., and Rauch, M. (1996) *Astrophys. J.* **465**, L95–L98.
11. Hernquist, L., Katz, N., Weinberg, D. H., and Miralda-Escudé, J. (1996) *Astrophys. J.* **457**, L51–L55.
12. Hu, E. M., Kim, T.-S., Cowie, L. L., and Songaila, A. (1995) *Astr. J.* **110**, 1526–1543.
13. Jakobsen, P., Boksenberg, A., Deharveng, J. M., Greenfield, P., Jedrzejewski, R., and Paresce, F. (1994) *Nature* **370**, 35–39.
14. Katz, N., Weinberg, D. H., Hernquist, L., and Miralda-Escudé, J. (1996) *Astrophys. J.* **457**, L57–L60.
15. Lanzetta, K. M., Bowen, D. B., Tytler, D., and Webb, J. K. (1995) *Astrophys. J.* **442**, 538–568.
16. Lu, L., Sargent, W. L. W., Womble, D. S., and Barlow, T. A. (1996) *Astrophys. J.* **457**, L1–L4.
17. Madau, P. and Meiksen, A. (1994) *Astrophys. J.* **433**, L53–L56.
18. Miralda-Escudé, J. (1993) *Mon. Not. R. astr. Soc.* **262**, 273–276.
19. Miralda-Escudé, J. and Rees, M. J. (1994) *Mon. Not. R. astr. Soc.* **266**, 343–352.
20. Pei, Y. C. and Fall, S. M. (1995) *Astrophys. J.* **454**, 69–76.
21. Pettini, M., King, D. L., Smith, L. J., and Hunstead, R. W. (1996) *Astrophys. J.*, in the press.
22. Pettini, M., Smith, L. J., Hunstead, R. W., and King, D. L. (1994) *Astrophys. J.* **426**, 79–96.
23. Reisenegger, A. and Miralda-Escudé, J. (1995) *Astrophys. J.* **449**, 476–487.
24. Shull, J. M., Stocke, J. T., and Penton, S. (1996) *Astr. J.* **111**, 72–77.
25. Songaila, A. and Cowie, L. L. (1996) *Astr. J.* **112**, 335–351.
26. Songaila, A., Hu, E. M., and Cowie, L. L. (1995) *Nature* **375**, 124–126.
27. Stocke, J. T., Shull, J. M., Penton, S., Donahue, M., and Carilli, C. (1995) *Astrophys. J.* **451**, 24–43.
28. Storrie-Lombardi, L. J., McMahon, R. G., and Irwin, M. J. (1996) *Mon. Not. R. astr. Soc.*, in the press.
29. Tytler, D., Fan, X.-M., Burles, S., Cottrell, L., Davis, C., Kirkman, D., and Zuo, L. (1995) In *QSO Absorption Lines*, Meylan, G., editor, pp. 289–298, Springer, Heidelberg.
30. Wampler, E. J., Williger, G. M., Baldwin, J. A., Carswell, R. F., Hazard, C., and McMahon, R. G. (1996) *Astr. Astrophys.*, in the press.
31. Zhang, Y., Anninos, P., and Norman, M. L. (1995) *Astrophys. J.* **453**, L57–L60.

DARK MATTER AND GRAVITATIONAL LENSING

EDWIN L. TURNER
Princeton University Observatory, Princeton, NJ 08544 USA

1. Introduction

The study of dark matter and other topics of cosmological importance via study of gravitational lens systems has continued to grow rapidly in importance and diversity during the past three years. An IAU Symposium on the astrophysical applications of gravitational lensing was held in Melbourne during July 1995, and its proceedings contain an extensive review of developments up to that time. This report will therefore concentrate primarily on progress during the most recent year of the subject period.

2. Microlensing in the Galactic Halo

The most dramatic and potentially most significant result of the last year, and in fact perhaps of the whole period, is the MACHO group's report of a microlensing rate for stars in the Large Magellanic Cloud which exceeds that expected from known Galactic populations by a factor of several. The observed rate is, in fact, within a factor of two or so of that expected (and predicted a priori!) if the Galaxy's dark halo were composed of compact, roughly stellar mass objects (MACHOs). Accepted at face value, this observation may well constitute a first direct detection of the individual objects making up a significant fraction of the dark matter in the Universe and would indicate that they are not separate elementary particles as expected by many, but in fact very macroscopic objects!

However, of course, there are a number of caveats and potential problems which prevent one from drawing these grand conclusions with confidence at this stage. Although there seems to be little doubt that the photometric events observed by the MACHO group are indeed produced by gravitational microlensing, their precise interpretation is problematically model dependent. Furthermore, even within the standard model adopted by the MACHO group, the observations are surprising and troubling in one important respect, namely the masses of individual microlensing objects implied by the duration of the photometric events is in the range of a few tenths of a solar mass. This is just the mass range in which massive objects (at least those made of baryons) are not dark! This issue is exacerbated by the fact that the distribution of event durations suggests that additional mass may well be present in individually larger mass objects than those to which the present survey is most sensitive. In other words, although the rate of events is much higher than that expected from known stellar populations, the distribution of event durations looks rather like that which would be produced by a normal stellar population. This raises the possibility that it is not dark matter but rather a previously unknown or simply underestimated stellar population which is responsible for the high event rate. Since the object masses are much more sensitive to the details of the assumed halo model than are the total mass implied by the event rate, this puzzle may only be an indication that the simple theoretical halo model used to interpret the data is inadequate. It could also be that nature has somehow conspired to produce a very large number of very dark stars (old white dwarfs have been suggested) in galactic halos. It might be that the line-of-sight to the LMC is unrepresentative in some way (an intervening dwarf galaxy, for example).

Whatever the ultimate outcome of the extensive investigations of LMC microlensing events that are sure to follow this first exciting result, it seems certain that we will gain important information on the nature of dark matter in the Galactic halo, either through positive or null results.

3. Dark Matter Maps of Rich Galaxy Clusters

Aside from the MACHO result, the next most direct information on dark matter from gravitational lensing comes from the study of lensing distortions of faint, primarily blue, background galaxies by foreground rich galaxy clusters. These distortions can be either strong, producing so called luminous arcs, or weak, and thus only detectable statistically over many individual object images. This technique has now reached a high degree of technical development, both observationally and theoretically. It is now relatively routine to map the dark matter distributions in rich clusters with a resolution comparable to the separation between background source images. The results, now available for a hand full of clusters, show that the mass of galaxy clusters is indeed dominated by some unseen component spread far more smoothly than the luminous (stars in galaxies) material but that this dark component is by no means perfectly smooth and is often correlated in its distributions with inhomogeneities of the visible galaxy distribution. In many ways, these conclusions simply confirm inferences from other types of observations (in visible and x-ray bands), but they are supported more directly and robustly by the lensing studies.

4. Cosmic Large Scale Structure and Dark Matter

Considerable effort has been directed toward applying similar weak lensing techniques to the mapping of the cosmic mass distribution on much larger scales outside individual rich galaxy clusters by studying the very weak orientation correlations of faint galaxies on large angular scales (of degrees). Although the technique has great promise and has been studied extensively theoretically, it has not yet been possible to obtain a compelling and reproducible observational result. This line of investigation is still in its infancy but may soon yield important information on the role of dark matter in cosmic large scale structure.

5. Gravitational Lensing and Cosmological Parameters

Finally, it is worth noting that gravitational lens observations are playing an increasingly important role in attempts to measure cosmological parameters. The frequency of quasar lensing by foreground galaxies places one of the best available limits on the value of the cosmological constant. If one assumes a flat, zero curvature, universe, the lensing limits indicate that the present universe can at most be only mildly dominated by a cosmological constant according to the most recent studies. This in turn implies that only modest relief from the cosmic age crisis can be obtained by appeal to non-zero cosmological constant models. As the differential time delay between one pair of gravitational lens images (0957+561A,B) now seems to have been determined reasonably definitively, it appears that Refsdal's method for determining the Hubble constant may finally become practical; thus, gravitational lensing would provide another key constraint in cosmic age considerations.

ALTERNATIVE COSMOLOGIES

J.V. NARLIKAR
Inter-University Centre for Astronomy and Astrophysics
Post Bag 4, Ganeshkhind, Pune 411 007, INDIA

The hot big bang models with inflation (in some form or other) being the favourite amongst the cosmologists, the development of alternative models has been confined to very few workers. Nevertheless, the HST measurements of Hubble's constant, and their implications for the age of the universe, underscored the need to think beyond the standard model. Ostriker and Steinhardt (1995) for example have concluded that the present data favour a low matter density model ($\Omega_m < 1$) with a non-zero cosmological constant ($\Omega_\Lambda > 0$). The latter, however cannot exceed 0.75, if the data on gravitationally lensed sources is taken into account. A similar conclusion is drawn by Bagla et al (1996) who have also taken into consideration the constraints from structure formation, deuterium abundance,the data on high redshift objects, cluster abundance, etc. These authors find that even with the allowances made for observational errors, the window of available parameters for the conventional big bang models is uncomfortably small if not non-existent. A detailed study by Viana and Liddle (1996) has discussed implications for flat and open cosmological models using the data on cluster abundance, COBE, galaxy correlation function, etc.

Meanwhile theoreticians working on the particle physics-cosmology frontier have been looking at cosmological models based on string theory. Gasperini and Veneziano (1993) discuss possible non-singular models with a *pre- big bang* phase of accelerated evolution. Cosmological implications of dynamical supersymmetry breaking such as big bang nucleosynthesis, are discussed by Banks et al (1994). Brustein and Veneziano (1994) discuss the long standing graceful exit problem within the string cosmology. The answer is still non-definitive. The vanishing of the cosmological constant in the post-inflation era continues to occupy the astro-particle theorists.

Amongst alternative to dark matter in cosmology the idea discussed most in recent times is modified nonrelativistic dynamics (MOND). Milgrom (1994) has reviewed the status of MOND theories both from a theoretical point of view as well as observations of the flat rotation curves of spirals.

To what extent the universe has fractal dimension has been reviewed by S. Borgani (1996) who finds that the universe behaves like a self-similar structure at small scales, where fractality is generated dynamically by non-linear gravitational clustering while preserving large scale homogeneity. Souriau (1994) and his coworkers have attempted to understand structure on the scale of 100 Mpc as due to a primordial symmetry breaking giving stratification.

Evidence which cannot be explained by the conventional cosmological redshifts continues to come forth. Arp (1994), for example has analysed the ROSAT pictures to claim physical association between Cen A and NGC 5090. Burbidge (1995) has measured the redshifts of two x-ray QSOs from the ROSAT PSPC data aligned within 36 arcsec across the nucleus of NGC 4258 and finds them to be 0.398 and 0.653 respectively. Pietsch et al (1994) who had carried out the first study of the data had concluded "...If the connection of these sources with the galaxy is real they may be bipolar ejecta from the nucleus."

It is becoming increasingly difficult to ignore these associations as chance projection effects, which they have to be if the redshifts follow Hubble's law. Likewise, the earlier findings of small scale periodicities in the redshift distributions of galaxies by Tifft, reviewed by him recently (1995), appear to hold up under stringent statistical tests. For example, Napier and Guthrie (1993) have shown that a periodicity of 37.5 km/s is seen to a high level of significance in the local supercluster. These observations may pose a stiff challenge to any cosmological theory, standard or otherwise.

An alternative cosmology using the conventional redshift but without a singularity is the quasi-steady state cosmology proposed by Hoyle et al and developed in several papers (e.g.,1994 a,b, 1995). It offers an alternative interpretation of the microwave background, abundances of light nuclei and dark matter while claiming consistency with the data on ages of globular clusters, optical and radio surveys of discrete sources. This cosmology also predicts the existence of a modest fraction of low-blueshift objects.

References

1. Arp, H.C. (1994) *Astron. Astrophys.*,**288**,738
2. Bagla, J.S., Padmanabhan, T. and Narlikar, J.V. (1996) *Comm. Asp.&Sp.Phys*, **18**,275
3. Banks, T., Kaplan, D.B. and Nelson, A.E. (1994) *Phys.Rev.*, **D 49**,779
4. Borgani,S. (1995) *Phys.Reports*,**251** ,1

5. Brustein,R. and Veneziano,G. (1994) *Phys.Lett.*, **B 329**,429
6. Burbidge,E.M. (1995) *Astron. Astrophys.*, **298**, L1
7. Gasperini,M. and Veneziano,G. (1993) *Astropart.Phys.*,**1**,317
8. Hoyle, F.,Burbidge, G. and Narlikar, J.V. (1994a) *MNRAS*,**267**,1007
9. Hoyle, F.,Burbidge, G. and Narlikar, J.V. (1994b) *Astron. Astrophys.*, **289**, 729
10. Hoyle, F.,Burbidge, G. and Narlikar, J.V. (1995) *Proc. Roy. Soc. A*, **448**,191
11. Milgrom, M. (1994) *Ann. Phys.(N.Y.)*, **229**, 384
12. Napier,W.M. and Guthrie,B.N.G. (1993) in *Progress in New Cosmologies,* Proceedings of the 13th Cracow Summer School of Cosmology;Eds H.C. Arp, C.R. Keys,K. Rudnicki,p.29
13. Ostriker, J. and Steinhardt, P.J. (1995) *Nature*, **376**, 600
14. Pietsch,W.,Vogler,A.,Kahabka,P.,Jain,A.& Noreau,L. (1994) *Astro. Astrophys*,**284**,386
15. Souriau,J.M. (1994) Science et Vie -Hors Serie *le Big Bang en question*, **189**, 132
16. Tifft, W.G. (1995) *Astrophys. and Sp. Sc.*, **227**, 25
17. Viana, P.T.P. and Liddle, A.R. (1996) *MNRAS*, **281**, 323