40. RADIO ASTRONOMY (RADIO ASTRONOMIE)

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I. INTRODUCTION.

(G. SWARUP, TIFR, Ootacamund)

This report covers surveys of radio sources, basic measurements of source parameters and new developments in radio telescopes, instrumental techniques and data processing. The period covered is approximately late 1978 to about August 1981. The results and conclusions of astronomical investigations based on measurements made through the radio window are included in the reports of other commissions, as relevant. Following the practice adopted in 1979, a circular was sent to the Presidents of 18 IAU Commissions and to all members of Commission 40 describing the proposed format of the present report and also identifying contact persons who could be consulted to avoid duplication and to ensure that radio astronomical results are adequately covered by various commissions. I am grateful to all concerned for providing the necessary coordination.

Since measurements of Galactic radio sources, both in continuum and in spectral lines, are generally covered fairly adequately by other IAU Commissions, more emphasis has been given in the present report on extragalactic radio sources. The report does not attempt to provide a comprehensive bibliography due to limitations of space and time. The objective has been to highlight the progress made and to provide key references according to the judgement of the authors of different sections. I would like to express my gratitude to the authors for the excellent work done by them and thank V.K. Kapahi for his help in putting the report together.

A list of important international conferences/symposia/advanced courses relevant to radio astronomy, either held during the period or for which the proceeding have been published in the period is given below.

Active Galactic Nuclei: Proc. Nato Advanced Study Institute, August 1977; Cambridge Univ. Press 1979; (eds.) C. Hazard and S. Mitton.

Extragalactic High Energy Astrophysics: 9th Advanced Course, SAAS-FEE, 1979, (eds.) A. Blecha and A. Maeder.

The Universe at Large Redshifts: Proc. Copenhagen Symp., June 1979, (eds.) J. Kalckar, O. Ulfbeck and N.R. Nilsson, Phys. Scr. Vol. 21, pp 599-781, 1980.

Physical Cosmology: Les Houches Summer School, July 1979, North Holland 1980, (eds.) R. Balian, J. Audouze and D.N. Schramm.

Objects of High Redshifts: IAU Symp. No.92, Los Angeles, August 1979, (eds.) G.O. Abell and P.J.E. Peebles.

https://doi.org/10.1017/S0251107X00005046 Published online by Cambridge University Press

Radio Physics of the Sun: IAU Symp. No.86, College Park Md., August 1979, (eds.) M.R. Kundu and T.E. Gergely.

Interstellar Molecules: IAU Symp. No.87, Mont Tremblant, Quebec, August 1979, (ed.) B.H. Andrew.

Radio Recombination Lines: Proc. Workshop held in Ottawa, August 1979, D. Reidel, (ed.) P. Shaver.

Origin of Cosmic Rays: IAU Symp. No.94, Bologna, June 1980, (eds.) G. Setti, G. Spada and A.W. Wolfendale.

Pulsars: IAU Symp. No.95, Bonn, August 1980, (eds.) W. Sieber and R. Wielebinski.

Tenth Texas Symp. on Relativistic Astrophysics: Baltimore, Dec. 1980.

Optical Jets in Galaxies: Proc. 2nd ESO/ESA Workshop, Munich, February 1981.

Extragalactic Radio Sources: IAU Symp. No.97, Albuquerque, August 1981, (eds.) D. Heeschen and C.M. Wade.

II. SURVEYS.

(I.I.K. PAULINY-TOTH, MPIfR, Bonn)

This report is concerned with basic surveys, but not with measurements of specific objects.

a) Galactic Surveys.

A 30 MHz map of the whole sky, obtained by combining medium resolution surveys, and intended to help studies of large-scale galactic features, has been made by Cane (78 AJP 31, 561). An all-sky map at 408 MHz, smoothed to a resolution of 3° has been presented by Haslam et al. (80 IAU Symp No 94, p 217); this is based on an all-sky survey made with a beam of 51'arc, a description of the final sections of which has been published (81 AA 100, 209), the complete Atlas being in press (AA Sup).

A section of the galactic plane ($93° \leq \ell \leq 162°$, $|b| \leq 4°$) has been surveyed at 1420 MHz with 9 arcmin resolution by Kallas and Reich (80 AA Sup 42, 227) and has yielded a list of 236 sources > 0.3 Jy. An all northern sky survey at this frequency, made with lower resolution (36 arcmin), has been completed by Reich et al. and is awaiting publication (AA Sup).

A survey of the Upper Scorpio region (15h 43m $\leq$ RA $\leq$ 16h 40m, $-35° \leq \delta \leq -15°$) has been made at 2295 MHz with a beamwidth of 20 arcmin by Baart et al. (80 AA 92, 156).

At frequencies near 5 GHz, two major surveys have been made. Altenhoff et al. (79 AA Sup 35, 23) have surveyed the area $\ell = 357.^{\circ}5$ to 60°, $|b| < 1°$, with a 2.6 arcmin beam and have detected 1186 sources with peak flux densities as low as 0.1 Jy. A complementary catalogue of 915 sources lying in the area $190° < \ell < 360°$, $|b| < 2°$, complete to 0.26 Jy for point sources, has been compiled from a previous survey by Haynes et al. (79 AJP Ap Sup 48, 1). Also near 5 GHz, Gregory and Taylor are surveying an area along the galactic plane ($40° < \ell < 220°$, $|b| < 2°$) repeatedly, down to a level of 10 mJy, in a search for compact and variable radio sources (81 ApJ 248, 596).

At mm and sub-mm wavelengths, Owens et al. (79 ApJ 231, 702) have made a survey,

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from balloon altitudes, of about 3 sr with a 1°.6 beam, in the range 3 to 10 cm^{-1} and 10 to 25 cm^{-1}, and have detected part of the galactic plane.

The large-area surveys at 408 and 1420 MHz promise fruitful results in the analysis of the distribution and spectrum of the galactic radiation. The 5 GHz surveys have led to many subsequent spectroscopic investigations.

b) Extragalactic Surveys.

At decametric wavelengths, two further sections of the UTR2 survey by Braude et al. have been completed, covering the declination ranges 0° to 10° (79 ApSpS 64, 73) and -2° to -13° (81 ApSpS 74, 409). They include 680 sources for which flux densities in the range of frequencies from 12.6 to 25 MHz are given. These decametric surveys now cover the declination range -13° to +20°. A synthesis survey of the celestial polar cap has been carried out by Dewdney (79 JRASC 73, 303) and covers declinations north of 70° to a flux density of 4.5 Jy at 22 MHz.

The 151 MHz "6C" survey mentioned in the 1979 Reports has been completed; the first section, covering the celestial north-polar cap, and including some 2000 sources stronger than 100 mJy is awaiting publication.

The Ooty lunar occultation survey at 327 MHz has continued with lists 7 (Singal et al. 79 MemAS India 1, 14), 8 (Venkatakrishna and Swarup 79 ibid 1, 25) and 9 (Joshi and Singal 80 ibid 1, 49). These occultation surveys list about 420 sources stronger than 0.2 Jy, observed with a resolution of ∿ 6 arcsec.

At 365 MHz, the first results of the Texas Survey (UTRAO) have been presented, for a strip covering the declination (1975.4) range 13°.6 to 22°.7 (Douglas et al. 80 Univ Texas Publ Astr No 17). This first section lists 7250 sources stronger than 0.15 Jy, for which a positional accuracy of 1 × 0.5 arcsec has been achieved - a very promising combination of sensitivity and resolution at long wavelengths. The complete survey is expected to include some 70,000 sources.

The Molonglo surveys, carried out at a frequency of 408 MHz, have been used to prepare a reference catalogue of over 12,000 sources above a limiting flux density of 0.7 Jy. The catalogue is complete above 1 Jy and gives radio positions accurate to a few arcsec (Large et al. 81 MN 194, 693). The declination range is from -85° to +18°.5.

A list of 242 sources (Porcas et al. 80 MN 191, 607) completes the data for a 966 MHz survey of the area 40° < δ < 71°. A total of 780 sources having flux densities > 0.7 Jy have been found in this survey.

The "5C" areas 1 to 5 have been resurveyed by Gillespie (79 MN 188, 481) and systematic errors in the positions and flux densities quoted in the original 5C surveys have been found.

From a survey at 4.85 GHz, Maslowski et al. (81 AA 95, 285) find that flux density errors dependent on radial distance may be present also in the 5C6 survey.

The 5C12 survey (complete to 9 mJy at 408 MHz, with deep optical identification work) by C. Benn is in press. A sensitive Westerbork survey at 1.4 GHz has been made down to about 1 mJy in an Eeinstein observatory field and with Supporting deep optical identification work (Windhorst 81 IAU Symp 97).

At centimetre wavelengths results of previous surveys have been consolidated, and the data extended into the mJy range. Peacock and Wall (81 MNRAS 194, 331) have used the Parkes 2.7 GHz surveys and the NRAO-MPIfR 5 GHz surveys to compile a northern hemisphere catalogue of bright extragalactic sources. The catalogue contains 168 sources having flux densities > 1.5 Jy at 2.7 GHz, all of which have been observed with the Cambridge 5 km synthesis telescope; for 93 percent, identifications with optical objects have been possible and for 64 percent redshifts are available.

A similar catalogue of bright sources has been compiled for the frequency of 5 GHz by Kühr et al. (81 AA Sup 45, 367). This covers both hemispheres down to a limiting flux density of 1 Jy at 5 GHz and includes 518 sources for which radio spectra and optical information is given. The catalogue is itself a subsample of a more extensive list of about 1800 sources (Kühr et al. 79 MPIfR preprint No 55) and includes the data from the most recent, and last section of the MPIfR "strong source" survey (Kühr et al., 81 AJ 86, 854).

The 5 GHz surveys have been extended to fainter sources by single-dish surveys complete to between 10 and 20 mJy (Pauliny-Toth et al. 80 AA 85, 329; Ledden et al. 80 AJ 85, 780; Pauliny-Toth et al. 81 AA in press). These surveys show that "convergence" of the source counts occurs at 5 GHz below 100 mJy. Statistical P(D) analyses of background deflections observed with the NRAO 91m telescope (Ledden et al. 80 AJ 85, 780) and with the Effelsberg 100m telescope (Maslowski et al. 81 AA 95, 285; Wall et al. 81 MPI preprint No.103) show that this convergence continues to a level of ∿ 1 mJy and that no "new" population of sources appears at these low flux densities. Direct counts to levels as weak as 4.5 mJy have been made using background sources detected in 89 fields observed with the Westerbork Synthesis Telescope (Willis and Miley, 79 AA Sup 37, 397 & 79 AA 76, 65). These are roughly consistent with the P(D) results.

The source counts at centimetre wavelengths are now satistically reliable; a considerable amount of information on radio spectra, identifications and redshifts exists. Studies of evolutionary models have been made and are continuing, and there is promise of considerable progress in this area over the next few years (eg. Wall 81 IAU Symp 97). In particular, ongoing observations with the Very Large Array are expected to extend the flux density range covered down to levels of some tens of μJy.

III. BASIC MEASUREMENTS.

a) Flux densities and radio spectra. (R. FANTI, Bologna)

Flux density measurements at various frequencies for several samples of radio sources over a large flux density interval have been reported. Radio sources from the 4C catalogue, in the declination range 20° to 40°, have been extensively measured at several frequencies (Veron and Veron 79 AA Sup 36, 331 at 318 MHz; Veron et al. 81 AA Sup 43, 195 at 2.7 and 5 GHz; Katgert-Merkelijn et al. 80 AA Sup 40, 91 at 5 GHz). Flux measurements at 5 GHz for strong B2 sources (≳ 1 Jy) are given in Grueff and Vigotti (79 AA Sup 35, 371) and Katgert-Merkelijn et al. (80 op.cit), and, for Ooty sources, by Gopal-Krishna and Witzel (80 AA 89, 169).

358 radiosources from the ± 4° declination strip of the 2.7 GHz Parkes catalogue have been measured at 408 MHz with the Bologna Cross (Grueff et al. 80 AA Sup 41, 21). High frequency observations of low frequency (408 - 1400 MHz) flat spectrum sources from the GB survey have produced high frequency spectra for about 200 sources up to 8 GHz (Machalski and Condon 79 AJ 84, 164). Witzel et al. (81 AJ 84, 942) give flux densities for 345 sources of the NRAO-MPI 6 cm survey.

At very weak radio fluxes (≥ 10 mJy) J. Katgert (79 AA 73, 107) has presented two-frequency spectra, between 1.4 and 0.6 GHz for a complete sample of about 80 sources.

https://doi.org/10.1017/S0251107X00005046 Published online by Cambridge University Press

A useful compilation containing spectral information for over 1500 sources has been produced by Kühr et al. (MPIfR preprint No.55). All the flux densities are adjusted to the flux scale of Baars et al. (77 AA 61, 99). A subset of it, containing sources stronger than 1 Jy at 5.0 GHz has been published (Kühr et al. 81 AA Sup 45, 367).

A particular emphasis has been recently given to simultaneous multifrequency flux measurements, obviously in connection with radio variability (see e.g. Owen et al. 80 AJ 85, 351; Jones et al. 81 ApJ 243, 97; Mingaliev et al. 79 Astrofiz 14, 91).

b) Radio variability. (R. FANTI, Bologna)

i) Flux monitoring.

Galactic sources: A survey of variable galactic sources in the galactic plane is being made by Gregory and Taylor (79 JRASC 73, 303; 81 ApJ 248, 596). SS 433 has been monitored at several wavelengths. Variations of a factor 4 in about 10 days have been found by Heeschen and Hammond (79 ApJL 235,L129). Bonsignori-Facondi (81 preprint), based on regular monitoring at 408 MHz over more than a year, shows that the flux changes periodically, with the fundamental period of the object.

Extragalactic sources: Results from monitoring of samples of compact (< 1") extragalactic radio sources have been reported at several frequencies (Landau et al. 80 AJ 85, 363 for 55 sources and Epstein et al. 80 AJ 85, 1427 for 33 sources at 90 GHz; Webber et al. 80 AJ 85, 1434 and Wardle et al. 81 AJ 86, 848 at 18 cm; Fanti et al. 79 AA Sup 36, 359 and 81 AA Sup 45, 61 at 408 MHz; Condon et al. 79 AJ 84, 1 at 318 MHz; McAdam 80 PASAust 4, 70 at 408 MHz; Erickson and Fisher 81 ApJ 242, 884 in the range 0.3-1.0 GHz; Spangler and Cotton 81 AJ 86, 730 in the range 0.3-15 GHz).

From the above studies it appears now that variability is equally common at all wavelengths. In particular, definite evidence has been obtained on the reality of variability at long wavelengths (λ > 20 cm.), on which doubts were often previously raised, both because of the lack of independent and simultaneous observations and because of the interpretational problems which are raised.

Reviews on variability of extragalactic radio sources and related problems are found in Fanti and Salvati (80 Proc. 5th Europ. reg. meeting astr., Liege) and Kellermann and Pauliny-Toth (82 ARAA 19, 373).

Searches for variability in central components of double radio galaxies and quasars have been made by Hine and Scheuer (80 MN 193, 285) and by Ekers et al. (81 preprint). Radio variability is found frequently in the case of radio galaxies and less frequently in the case of quasars, where, however, it tends to be hidden by larger measurement errors.

ii) Time scale of variability.

At all wavelengths variability occurs on typical intervals of few months to few years. At very short wavelengths daily and hourly variations have been searched by Epstein et al. (80 AJ 85, 1427). Most sources did not exhibit significant variations, but OV-236 showed a flux change by a factor 2.7 in a three day interval. At decimeter and meter wavelengths (Fanti et al. 79 AA Sup 36, 359; Spangler and Cotton 81 AJ 86, 730; Wardle et al. 81 AJ 86, 848) the fastest variations seen are of the order of 1 - 2 months. Brightness temperatures, deduced from the "causality" argument for sources varying at dm wavelengths generally exceed 10^{12}K by several orders of magnitude.

iii) Spectral behaviour of variations.

Epstein et al. (81 preprint) have examined the outburst amplitude versus frequency in the mm and cm range. They find a variety of situations, ranging from cases where amplitudes are almost independent to cases were they are strongly dependent on wavelength.

Still unclear is the situation of variability at dm and m wavelengths. These phenomena, although being broad-band, seem disconnected with the cm variability (see Cotton and Spangler 79 ApJL 228, L63; Fanti et al. 81 IAU Symp 97).

iv) Correlations with optical and X ray variations.

Correlations with optical variability (Pollock et al. 79 AJ 84, 1658; Pica et al. 80 AJ 85, 1442) generally are inconclusive. In the case of PKS 0420-01 (Dent et al. 79 ApJL 227, L9) and of NGC 1275 (Lyutyi 80 Sov Astr L 6, 122) delays of about 2 years have been suggested between radio and optical variations, leading to the conclusion that the two phenomena occur in separate regions. In the case of 0235+164 (Balonek and Dent 80 ApJL 240, L3) and of 1921-29 (Gilmore 80 Nature 287, 612) a coincidence was seen between a radio and an optical outburst. The simultaneity in this case indicates a common origin.

A search for X ray emission from variable radio sources using HEAO-1 data has been made by Marscher et al. (79 ApJ 233, 498). The X ray fluxes expected on the basis of the time scale of variability are several orders of magnitude greater than the observed fluxes or limits, implying that sizes are larger than those deduced from time scale of variability.

v) Polarization.

Studies of linear polarization related to variability are presented by Aller et al. (81 AJ 86, 325) for 14 sources. The most impressive results are those showing rotation of polarization angle for 0727-115 and BL Lac, over substantially more than 180°. See also Altschuler (80 AJ 85, 1559) and Ledden and Aller (79 ApJL 229, L1) for similar results. The suggested explanation is a rotation in the radio emitting region.

The importance of circular polarization measurements for compact radio sources has been emphasized by Weiler and de Pater (80 AA 91, 41). They present a complete sample of compact sources for which circular polarization measurements are available and show that about a quarter of them are detected. For one source, 0316+162 (CTA 21), the change in sign expected as the source changes from being optically thick to optically thin is clearly seen.

c) Brightness distributions.

i) Extended sources. (A. BRIDLE, Queen's Univ, Kingston)

With the addition of the VLA and MTRLI to the complement of image-forming radio telescopes and the development of procedures for high-dynamic-range mapping with the Bonn 100 metre radio telescope, the literature of structure measurements has become very extensive. Only a few aspects are mentioned explicitly here. The four major parts of typical extended sources are (1) small-diameter "cores" in the optical objects, (2) "jets" linking these to (3) diffuse "lobes" which in low-luminosity sources are relaxed in structure and limb-darkened but in higher-luminosity sources may contain (4) compact "hotspots" and are limb-brightened. Jets form the topic of Section (ii) below. For recent reviews of extended source structures see Miley (80 ARAA 18, 165) and Fomalont (80 IAU Symp 94).

Sources which are distorted from the basic linear shape (I structure) of extragalactic sources may have either "inversion" or "mirror" symmetries (S or C structures). Ekers (81 IAU Symp 97), Ekers et al. (81 AA 94, 61) and Shaver et al. (81 IAU Symp 97) examine the incidence of these distortions in complete samples of radio galaxies. They conclude that (a) the amount of distortion increases with decreasing radio luminosity, (b) S symmetry is most likely to occur in isolated multiple-galaxy systems and (c) rich cluster environments convert all morphologies to C symmetry.

Total and polarized intensity distribution over many of the brighter and larger sources have been determined at several frequencies with resolutions of a few arc seconds or tens of arc seconds (e.g., Burch 79 MN 186, 293, 79 MN 186, 519 & 79 MN 187,187; De Young et al. 79 ApJ 228, 43; Fanti et al. 81 AA 94, 61; Gioia and Gregorini 79 AA Sup 36, 347; Högbom 79 AA Sup 36, 173; Laing 81 MN 194, 301 & 81 MN 195, 261; Strom and Willis 80 AA 85, 236; van Breugel 80 AA 81, 265, 80 AA 81, 275, 80 AA 88, 248 & 80 Ph.D Thesis Leiden Univ; van Breugel and Willis 81 AA 96, 332; Willis et al. 81 AA 95, 250; Wright 79 ApJ 228, 34). High frequency mapping with single dishes has provided similar data at arc-minute resolution for some sources of large angular size (e.g. Klein and Wielebinski 79 AA 72, 229; Strom et al. 80 AA 85, 36; Wall and Schilizzi 79 MN 189, 593). These studies provide maps of spectral index, of Faraday rotation and depolarization and hence of projected magnetic fields, over the nearer and larger sources. These in turn constrain models of the energy flow through, and evolution of, the major parts of the extended sources.

The 3C list is still the most intensively studied. New maps of 3C sources at one or more frequencies (in addition to those referred to above) have been given by Andernach et al. 79 AA 74, 93; Birkinshaw et al. 81 MN 197, 253; Bridle and Fomalont 79 AJ 84, 1679; Bridle and Vallee 81 AJ 86, 1165; Bridle et al. 81 AJ 86, 1294 & 81 ApJ 248, 499; Burns and Christiansen 80 Nature 287, 210; Dreher 81 AJ 86, 833; Downes 80 MN 190, 261; Fomalont et al. 79 AA 76, 106, 80 ApJ 237, 418 & 80 AJ 85, 981; Haschick et al. 80 ApJ 239, 774; Jones et al. 81 ApJL 247, L57; Kotanyi 80 AA 83, 245; Kronberg et al. 80 AJ 85, 973; Laing 80 MN 193, 427; Lonsdale and Morison 80 Nature 288, 66; Owen et al. 80 ApJL 239, L11; Perley and Johnston 79 AJ 84, 1247; Perley et al. 79 Nature 281, 437, 80 AJ 85, 499 & 80 AJ 85, 649; Reich et al. 80 AA 89, 204; Rudnick et al. 81 ApJ 246, 647; Spangler and Cook 80 AJ 85, 659; Wilkinson 81 IAU Symp 97; Willis and Schilizzi 79 AA 71, 253.

The structure of the radio galaxy Cygnus A has been studied over an exceptionally wide range of frequencies, from 150 MHz (Winter et al. 80 MN 192, 931) to 22 GHz (Berlin et al. 80 Pis'maAJ 6, 470; Dreher 79 ApJ 230, 687 & 80 AJ 86, 833) and 150 GHz (Kafatos et al 80 ApJ 235, 18). There is no evidence for spectral steepening of the lobes from 1 GHz to 150 GHz, but a bridge of emission between the lobes is much stronger at 150 MHz than at 2.7 GHz. Four large-diameter sources were mapped at 43 and/or 74 MHz by Perley and Erickson 79 AJ 41, 131.

Further examples of "giant" radio galaxies 1 Mpc or more in extent have been documented (Hine 79 MN 189, 527; Masson 79 MN 187, 253; Mayer 79 MN 186, 99; Ulrich et al. 80 Nature 288, 459). Possible far-outlying components of 3C sources are reported by Reich et al. 80 ApJL 235, L61; Salter and Haslam 80 AA 81, 240; and Stute et al 80 AA Sup 42, 299.

The distinction between "compact" and "extended" sources made commonly in the literature, and for convenience in this report, has been shown to be artificial by the detection of low-level extended emission associated with luminous compact sources (Kapahi 79 AA 74, L11; Kus et al. 81 MN 194, 527; Moore et al. 81 MN 197, 325; Perley and Johnston 79 AJ 84, 1247; Perley et al. 80 AJ 85, 649; Wardle et al. 81 AJ 86, 848; Wilkinson 81 IAU Symp 97).

Mapping surveys of clusters of galaxies have been made by Andernach et al. 80 AA Sup 41, 339 & 81 AA Sup 43, 155; Burns and Owen 79 AJ 84, 1478; Burns and Ulmer

https://doi.org/10.1017/S0251107X00005046 Published online by Cambridge University Press

80 AJ 85, 773; Burns et al. 81 AJ 86, 1; Gavazzi 79 AA 72, 1; Gavazzi and Perola 80 AA 84, 228; Kotanyi 80 Sup 41, 421; Harris et al. 80 AA 90, 283, 80 AA Sup 39, 215 & 80 AA Sup 42, 319; Perola and Valentijn 79 AA 73, 54; Perola et al. 80 AA 84, 245; Schallwich and Wielebinski 79 AA 71, L15; Valentijn 80 AA 89, 234; and Waldthausen et al. 79 AA Sup 36, 237). Singal et al. (80 MN 191, 581) report lunar occultation studies of clusters.

Detailed maps of "tailed" (C-shaped) sources in cluster environments have been made by Bridle et al. 79 AA 80, 201; Bridle and Vallee 81 AJ 86, 1165; Burns 81 MN 195, 523; Burns and Owen 80 AJ 85, 204; Burns et al. 79 AJ 84, 1683; Downes 80 MN 190, 261; Fanti et al. 81 AA 94, 61; Harris et al. 80 AA 90, 283; McHardy 79 MN 188, 495; Owen et al. 79 ApJL 229, L59; Robertson 80 Nature 286, 579 & 81 AA 93, 113; Simkin and Ekers 79 AA 84, 56; Simon 79 MN 188, 637; Valentijn 79 AA Sup 38, 319, 79 AA 78, 367 & 81 AA 102, 53; Vallee et al. 79 AA 77, 183 & 81 ApJ November 1; and van Breugel 80 AA 81, 275.

The reality of very extended cluster "haloes" has continued to be controversial. That in the Perseus cluster has been shown to be an artifact of earlier low-resolution data (Birkinshaw 80 MN 190, 793; Gisler and Miley 79 AA 76, 109) whereas some others have been confirmed (Ballarati et al. 81 AA 100, 323; Hanisch 80 AJ 85, 1565; Hanisch and Erickson 80 AJ 85, 183; Hanisch et al. 79 AJ 84, 946). Jaffe and Rudnick (79 ApJ 233, 453) searched for new haloes.

Structures of complete samples of quasars have been examined by Fanti et al. 79 AA Sup 35, 169; Potash and Wardle 79 AJ 84, 707 and Wills 79 ApJ Sup 39, 291. The "double quasar" 0957+561 A, B has been studied intensively in search of constraints on gravitational-lens models (Greenfield et al. 80 Nature 286, 865 & 80 Science 208, 495; Noble and Walsh 80 Nature 288, 69; Pooley et al. 79 Nature 280, 461; Roberts et al. 79 Science 205, 894).

Structural information for samples of sources studied by the method of lunar occultations has been reported by Subrahmanya and Gopal-Krishna 79 Mem AS India 1,2; Singal et al. 79 Mem AS India 1, 14; Venkatkrishna and Swarup 79 Mem AS India 1, 25 and Joshi and Singal 80 MemAS India 1, 49. Sources from these samples have been studied interferometrically by Menon 80 AJ 85, 1577.

Structures of sources identified with bright galaxies have been determined by Beck et al. 79 AA 72, 25 & 80 Nature 283, 272; Condon 80 ApJ 242, 894; de Bruyn and Hummel 79 AA 73, 196; Feretti and Giovaninni 80 AA 92, 296; Gioia and Gregorini 80 AA Sup 41, 329; Grave et al. 81 AA 98, 260; Hummel 80 AA Sup 41, 151 & 80 Ph.D Thesis, Groningen Univ; Klein and Emerson 81 AA 72, 229; Kotanyi 79 AA 74, 156 & 81 Ph.D Thesis, Groningen Univ; Kronberg and Biermann 81 ApJ 243, 89; Pfleiderer et al. 80 AA Sup 40, 351; van Albada 80 AA Sup 39, 283; van der Hulst et al. 81 AJ 86, 1175; Viallefond et al. 80 AA 82, 207. Structures of sources in disturbed galaxies have been determined by Fosbury and Wall 79 MN 189, 79; Ghigo 80 AJ 85, 215 and Kronberg et al. 79 ApJL 230, L194 & 81 ApJ 246, 751.

Structures of sources in Seyfert galaxies have been measured by Meurs and Wilson 81 AA Sup 45, 99; Ulvestad et al. 81 ApJ 247, 419; Ward et al. 80 MN 193, 563; Willis 79 AA 73, 354; Wilson 81 2nd ESO/ESA Workshop & 81 IAU Symp 97; Wilson and Willis 80 ApJ 240, 429 and Wilson et al. 80 ApJL 237, L61. Extended structures associated with BL Lac objects are reported by Danziger et al. 79 MN 188, 415 and Weiler and Johnston 79 MN 190, 269.

Other structure studies not referenced above include those of B2 radio galaxies by Grueff et al. 81 AA Sup 44, 241, of S4 survey sources by Kapahi 81 AA Sup 43, 381, of 4C sources by Rudnick and Adams 79 AJ 84, 437, of 4C sources with steep spectra by Tielens et al. 79 AA Sup 35, 153, and of strong sources at 5 GHz by Ulvestad et al. 81 AJ 86, 1010.

ii) Radio jets. (A. BRIDLE, Queen's Univ, Kingston)

About seventy extragalactic radio sources are now known to contain bright, well-collimated radio features extending from unresolved cores at the centres of their parent optical objects towards their more extended radio emission. Such features are usually called "jets" (although there is no direct evidence for flow of matter along them). They have been detected in sources spanning the full range of radio luminosity from weak nearby galaxies to powerful quasars. The jets are commonly presumed to be due to radiative losses in or around "energy pipelines" linking the cores of active galaxies and quasars to their extended emission, as envisioned in continuous-beam source models (Blandford and Rees 78 Phys. Scr. 17, 265).

Recent observations of the structures of large-scale (arcsec to several arcmin) jets in extragalactic sources have been reported by Birkinshaw et al. (81 MN 197, 253), Bridle (81 IAU Symp 97), Bridle et al. (79 ApJL 228, L9; 80 ApJL 241, L145; 81 ApJL 248, 499), Browne and Orr (81 in Opt. Jets in Galaxies, ESO/ESA Workshop), Burch (79 MN 186, 293; 79 MN 187, 187), Burns (81 MN 195, 523), Burns and Christiansen (80 Nature 287, 208), Burns and Owen (80 AJ 85, 204), Davies et al. (80 Nature 288, 64), Ekers et al. (81 AA 101, 194), Fanti and Parma (81 ESO/ESA Workshop), Feigelson (81 IAU Symp 97), Fomalont (80 IAU Symp 94), Fomalont et al. (80 ApJ 237, 418), Högbom (79 AA Sup 36, 173), Jones et al. (81 ApJL 247, L57), Laing (80 MN 193, 427), Masson (79 MN 187, 252), Neff (81 IAU Symp 97), Owen et al. (80 ApJL 239, L11), Perley (81 ESO/ESA Workshop), Perley et al. (79 Nature 281, 437; 80 AJ 85, 499), Potash and Wardle (80 ApJ 239, 42), Rudnick and Burns (81 ApJL 246, L69), Saunders et al. (81 MN 197, 253), Schreier et al. (81 ApJ in press), Vallee et al. (81 ApJ Nov. 1), van Breugel (80 AA 81, 275; 80 Ph.D Thesis), van Breugel and Willis (81 AA 96, 332), and Willis et al. (81 AA 95, 250). Properties of the large-scale jets are reviewed by Miley (80 ARAA 18, 165), Willis (81 ESO/ESA Workshop) and Bridle (81 IAU Symp 97).

VLBI observations of asymmetric small-scale (sub-arcsec) jetlike structures near the radio cores of galaxies and quasars have been reported by Cohen and Readhead (79 ApJL 233, L101), Cohen et al. (81 ApJ 247, 774), Cotton et al. (81 ApJL 244, L57), Kellermann et al. (81 AA 97, L1), Linfield (81 ApJ 244, 436), Pauliny-Toth et al. (81 AJ 86, 371), Pearson and Readhead (81 ApJ 248, 61), Pearson et al. (80 ApJ 236, 714), Preuss et al. (80 ApJL 240, L10), Readhead (80 IAU Symp 92), Readhead and Wilkinson (80 ApJ 235, 11), and Simon et al. (80 ApJ 236, 707).

Large-scale jets occur in 70% to 80% of sources in complete samples of nearby radio galaxies from the B2 and 3CR radio surveys, but the detection rate in more powerful sources is lower (Ekers et al. 81; Fanti and Parma 81; Bridle 81). Jets may therefore make-up a smaller fraction of the total luminosity in the more powerful radio sources.

Observations of the internal structures of well-resolved jets show that they expand laterally at variable rates (Bridle et al. 79, 80; Bridle 81; Fanti and Parma 81, Feigelson 81; Perley et al. 79; Willis et al. 81). This presumably means that they are subject to some form of lateral confinement.

Observations of linear polarization in large-scale jets are reported by Birkinshaw et al. 81, Bridle et al. 79, 81, Burns 81, Burns and Christiansen 80, Burns and Owen 80, Fanti and Parma 81, Fomalont et al. 80, Laing 80, Owen et al. 80, Perley et al. 79, 80, Potash and Wardle 80, Saunders et al. 81, Vallee et al. 81, van Breugel 80a, b, van Breugel and Willis 81 and Willis et al. 81. In well-resolved jets, degrees of polarization from 30% to 40% are common at wavelengths shorter than 21cm, and polarizations as high as 65% have been detected (Willis et al. 81). Such high polarizations imply well-ordered magnetic structures in the jets. This is confirmed by direct mapping of the projected magnetic field structures in well-resolved jets (Bridle 81, Burch 79b, Fanti and Parma 81, Fomalont et al. 80, Willis et al. 81). The projected fields are generally either perpendicular to, or parallel to, the axes of extension of the jets; perpendicular fields dominate in jets produced by low-luminosity cores, while parallel fields dominate in jets produced by high-luminosity cores (Bridle 81).

Elongated structures resembling abbreviated jets have been reported in two Seyfert galaxies (Booler et al. 81 MN in press; Johnston et al. 81 ApJL in press; Wilson 81 IAU Symp 97).

iii) Compact sources (VLBI). (K.I. KELLERMANN, NRAO)

Recent improvements in image formation techniques using radio telescope arrays having baselines of thousands of kilometers now permit pictures of compact radio sources to be made with resolutions better than one milliarcsecond. "Closure-phase" or "self-calibration" techniques are used to eliminate the phase distortion introduced by the fluctuations in atmospheric path length (Cotton 79 AJ 84, 1122; Readhead et al. 80 Nature 285, 137; Schwab 80 SPIE J 231, 18; Rogers 80 SPIE J 231, 10). Multiple telescope arrays have been used at wavelengths ranging from 7 mm (Genzel et al. 79 ApJL 231, L73) to 91 cm (Simon et al. 80 ApJ 236, 707) to map quasars, galactic nuclei, interstellar molecular masers, and compact galactic radio sources.

Extragalactic sources: The observations of quasars and galactic nuclei generally show a core-jet morphology (Readhead 80 IAU Symp No.93, p 28; Pearson et al. 80 ApJ 236, 714; Readhead and Wilkinson 80 ApJ 235, 11; Wilkinson et al. 79 ApJ 232, 365; Kellermann 80 Ann Acad Sci N.Y. 336, 1; Pauliny-Toth et al. 81 AJ 86, 371; Baath et al. 81 ApJL 243, L123 & 80 AA 86, 364; Matveyenko et al. 80 Piz Astr Zh 6, 77; Preuss et al. 79 AA 79, 268; Readhead et al. 79 ApJ 231, 299; Kellermann and Pauliny-Toth 81 Ann RAA 19, 373). In a few cases, however, sources with a sharp low frequency spectral cutoff show compact symmetric double structure which is remarkably similar to the extended double sources (Phillips and Mutel 81 ApJ 244, 19 & 79 ApJ 236, 89). Of particular interest are the observations of apparent superluminal velocities in several quasars and galactic nuclei (Marsher 80 PASP 92, 127; Cohen et al. 79 ApJ 231, 293).

Many classical extended radio sources also contain central compact sources which show the same core-jet morphology as the strong compact sources. In general these central components are coincident with the identified galaxy or quasar along the line joining the more extended structure (Linfield 81 ApJ 244, 436; Kellermann et al. 81 AA 97, L1; Gopal-Krishna et al. 80 Nature 288, 344; Cohen and Readhead 79 ApJL 233, L101; Kapahi and Schilizzi 79 AA Sup 38, 11; Schilizzi et al. 79 AA 77, 1).

The compact structure in the double quasar 0957+561 has been mapped with various VLBI systems (Haschick 81 ApJL 243, L57; Porcas et al. 81 Nature 289, 758 & 79 Nature 282, 385). Relative positions of close pairs are being measured to submilliarcsec accuracy (Shapiro et al. 79, AJ 84, 1459).

Several so-called "normal-galaxies" are also found to contain compact nuclei which have been observed with VLBI techniques (Jones et al. 81 ApJ 246, 28; Graham et al. 81 AA 97, 388; Shaffer and Marscher 79 ApJL 233, L105).

Structure $\lesssim$ 0.1 arcsec has been found by VLBI in the hotspots of several extended 3CR sources (Kapahi and Schilizzi 79 Nature 277, 610 & 79 AA Sup 38, 11).

Galactic sources: Compact galactic radio sources have also been observed with VLBI techniques. VLBI observations of SS433 show the same double structure seen at optical wavelengths. Motions are seen on a time scale of only one day (Schilizzi et al. 79 AA 79, L26 & 81 Nature 290, 318; Walker et al. 81 ApJ 243, 589.

Spectroscopic VLBI observations of OH and H_2O maser sources show a wealth of complex structure which gives important new insight into the location of the source of maser excitation and the process of star formation and evolution (Lada et al. 81 ApJ 243, 769; Haschick et al. 81 ApJ 244, 76; Bowers et al. 80 ApJ 242, 1088; Elmegreen et al. 80 ApJ 241, 1007; Fix et al. 80 ApJL 241, L95; Reid et al. 80 ApJ 239, 89; Downes et al. 79 AA 79, 233; Genzel et al. 79 AA 78, 239; Reid and Moran 81 Ann RAA 19, 231).

d) Optical and X-ray emission from extended sources.

(G.K. MILEY, Leiden Observatory)

Until recently our knowledge of the physics of extended extragalactic radio sources was obtained almost exclusively from the limited information that could be derived from radio continuum observations alone. During the last few years this situation has changed radically. Several observations have been made indicating the presence of appreciable optical and even X-ray emission from extended features (jets and hotspots) in radio sources.

In the case of radio hotspots, the correspondence of the radio and optical morphologies of the southern hotspot in the lobe of 3C 33 (Simkin 78 ApJL 222, L55; Rudnick et al. 81 ApJ 246, 647) shows that at least in one hotspot there is a definite association of optical and radio emission. Radio-optical coincidences have been reported for other hotspots (e.g. Saslaw 78 ApJL 222, L35; Crane et al. 81 ApJ submitted) and statistical arguments suggest that some of these associations may be real.

Optical observations of radio jets (Butcher et al. 80 ApJ 235, 749) have shown that the optical jets in M87 and 3C 273 are far from unique and X-ray measurements have demonstrated that the jets in M87 and Centaurus A have nonthermal spectra which probably extend continuously over more than eight decades of frequency (Schreier 81 Proc. 2nd ESA/ESO Workshop "Optical Jets in Galaxies", p 109 and references therein). The presence of nonthermal continuum emission in the optical and X-rays argues strongly that relativistic particles in extended radio sources are accelerated within the lobes. Optical jets in radio galaxies was the subject of an ESA/ESO workshop in 1981.

Not only do radio jets often have associated optical <u>continuum</u> emission but also since the last General Assembly a large body of evidence has shown that the relativistic plasma responsible for the synchrotron emission sometimes has <u>emission lines</u> closely associated with it. Detailed interrelationships have been found on a variety of spatial scales (e.g. Miley 81 2nd ESA/ESO Workshop p 9).

Several connections have been established between the kiloparsec-scale synchrotron emission and the narrow-line regions of active galaxies. The radio luminosities are correlated with both the luminosities and the widths of the [O III] lines (Wilson and Willis 80 ApJ 240, 429; Heckman et al. 81 ApJ 247, 403). Moreover, the line profiles indicate that the thermal material in the narrow line regions is flowing outwards (Heckman et al. 81 ApJ 247, 403). Detailed spatial correspondence has been observed between a radio jet and Hα emission on a scale of a few kiloparsec in the peculiar radio galaxy 3C 305 (Heckman et al. 81, in preparation).

On a larger scale strong optical line emission extending over $\sim$ 60 kpc was discovered from the lobes of the radio galaxy 3C 277.3 (Coma A) and these lines are closely connected with the knots and other features in the radio source (Miley et al. 81 ApJL 247, L5; Bridle et al. 81 ApJ 248, 499).

The various observations of optical radiation associated with extended radio sources, combined with recent radio studies of Seyfert galaxies (e.g. Ulvestad et al.

81 ApJ 247, 419), have illustrated further the similarities which exist between Seyferts, radio galaxies and QSOs and have reinforced the viewpoint in which all these phenomena are interpreted within the context of a unified scheme of active galaxies. Combination of radio and optical data provides a new method of studying particle acceleration processes as well as providing unique information about the physical conditions in the region of the extended radio emission.

e) Pulsars. (R.N. MANCHESTER, Radio Physics, CSIRO)

A total of 330 pulsars ranging in period from 33 milliseconds (the Crab pulsar) to 4.308 seconds are now known. In recent work a number of groups have investigated the pulse morphology, in particular, the pulse-to-pulse variations such as drifting subpulses and mode changing (e.g. Fowler et al. 81 AA 93, 54) and microstructure (e.g. Cordes et al. 81 ApJ in press). Weisberg et al. (81 AJ 86, 1098) searched for interpulses in a sample of 28 pulsars and found two at intermediate spacings. Flux densities and profile shapes measured at 102.5 and 61 MHz by Izvekova et al. (79 Astron Zh 56, 322) show that most pulsars have a low frequency spectral turnover at about 100 MHz. Integrated pulse shapes and polarizations are given for a sample of southern pulsars in a series of papers (e.g. Manchester et al. 80 MN 192, 153). Becker and Rankin (80 ApJ Sup 42, 143) have presented a statistical summary of the polarization properties of 18 pulsars which shows that the presence of orthogonal polarization states is almost universal.

A number of interesting results have resulted from pulse timing observations by several groups. Helfand et al. (80 ApJ 237, 206) presented timing data on 37 pulsars recorded over an eight-year interval. Analysis of these results (Cordes and Helfand 80 ApJ 239, 640) showed that there is a correlation between the strength of random timing irregularities and pulse period derivative. Following a timing program by Newton et al. (81 MN 194, 841) in which new period derivatives were obtained for 124 pulsars, full timing data is now available for more than 90% of the known pulsars. Three pulsars are now known to be members of binary systems (Taylor 81 'Pulsars', IAU Symp 95, p 361). The two recently discovered systems (PSR 0820+02 and PSR 0655+64) have almost perfectly circular orbits in contrast to PSR 1913+16 which has a highly eccentric orbit. In a recent paper Taylor and Weisberg (82 ApJ in press) describe in detail the observations of PSR 1913+16 which verify General Relativity to a high degree of precision, enable the determination of the mass of the pulsar and its companion (both close to 1.41 solar masses) and provide the first observational evidence for gravitational radiation.

Establishment fo the distance scale is critical to any discussion of the galactic distribution of pulsars. Measurements of HI absorption in the spectra of pulsars (Weisberg et al. 79 AA 77, 204 & 80 AA 88, 84; Manchester et al. 81 'Pulsars', IAU Symp 95, p 445) have given new distance limits or estimates for 16 pulsars. Using a microwave link interferometer Salter et al. (79 Nature 280, 477) have for the first time made a direct measurement of the annual parallax of a pulsar (PSR 1929+10) giving a distance estimate of about 50 pc.

A catalogue containing the principal observed and derived parameters for the 330 known pulsars has recently been compiled by Manchester and Taylor (81 AJ in press).

https://doi.org/10.1017/S0251107X00005046 Published online by Cambridge University Press

IV. RADIO TELESCOPES.

a) Single dishes. (A.T. MOFFET, Caltech)

Recent development of single-dish telescopes has been almost exclusively for observations at millimeter wavelengths. Notable new instruments have been the 7 metre antenna at Holmdel, New Jersey, and the first of the Caltech 10.4 metre antennas at Owens Valley, California. Each of these has been used effectively at wavelengths as short as 1.3 mm; the latter has a measured aperture efficiency of 0.42 at that wavelength (Wannier et al. ApJ 230, 149). Two larger telescopes have been readjusted or resurfaced to permit use of their central regions at millimeter wavelengths: the Effelsberg 100 m at λ = 7 mm (Wielebinski 81 reported at URSI Gen. Assly) and the Parkes 64 m at λ = 2.6 mm (Robinson 81 reported at URSI Gen. Assly). Large optical telescopes also continue to be used occasionally for millimeter and sub-millimeter observations (e.g. Kreysa et al. 80 ApJ 240, 117; van Vliet et al. 81 AA 101, L1).

In the next few years several new, large millimeter and sub-millimeter wave telescopes will begin operation. The largest of these is the 45 m dish at Nobeyama, Japan, with an r.m.s. surface error (σ) goal of 200 microns. It will be used at its prime focus for wavelengths between 4 and 30 cm and at a Gregorian-coude focus for λ < 4 cm. Its carbon fibre reinforced surface panels are mounted on motor-driven positioners, and a laser surveying system is built in, permitting frequent readjustment of the surface (Tanaka 81 reported at URSI Gen. Assly.; also Nobeyama Rad. Obs. Tech. Rep. No.6). A 30 m telescope with expected surface accuracy σ = 70 microns is under construction at Pico Veleta, Spain, by the Max Planck Institute for Radioastronomy. It will be operated, beginning in 1982, by the Institute for Radio Astronomy at Millimeter Wavelengths (IRAM), Grenoble. A similar telescope will be built on Mount Korek, Iraq, By the Council for Scientific Research of Iraq.

The Purple Mountain Observatory, Peoples' Republic of China, has begun the construction of a 15 m telescope in Chinghai Province, while the Science Research Council of the United Kingdom, with partial support from the Netherlands Foundation for Radio Astronomy, has designed a 15 m telescope (σ = 50 microns) which will be built on Mauna Kea, Hawaii. The Raman Research Institute is constructing a 10.4 m dish (using the Caltech design) at Bangalore, India. An improved Caltech 10.4 m, with σ = 15 microns as a design goal, is under construction and will ultimately be located on Mauna Kea. The venerable Kitt Peak 11 m telescope will be resurfaced in 1982, becoming a 12 m with $\sigma \leq$ 100 microns.

Notable advances have been made in the measurement of antenna surface profiles using RF techniques, either with transmitters in the near field or the far field (Mayer and Davis 81 reported at URSI Gen. Assly.; Godwin et al. 81 Int. Conf. Antenna & Propagation, York, IEE Conf. Publ. No. 195). Work has continued at NRAO on deformable subreflectors and on the effects of gravitational distortion on telescope performance (von Hoerner 80 IEEE Trans AP-28, 652). An absolute calibration of the effective collecting area of the Texas 5 m antenna at λ = 3.5 mm was carried out by Ulich et al. (80 IEEE Trans AP-28, 367).

b) Millimeter-wave Arrays. (A.T. MOFFET, Caltech)

Several millimeter-wave interferometers designed for solar studies have been in operation for a number of years (e.g. Bordeaux, Kyoto). The first millimeter-wave array capable of aperature-synthesis mapping of faint sources has been constructed at Hat Creek, California, and initial spectral-line maps from this instrument at λ = 3.5 mm have been published (Welch et al. 81 ApJL 245, L87). A third 6 m antenna will be added to this array in 1982. Surface error profiles of the first two antennas have been measured with an accuracy of better than 100 microns using the holographic technique of Scott and Ryle (Welch 81 reported at URSI Gen. Assly.).

The Owens Valley millimeter interferometer came into operation at λ = 2.6 mm in 1981, using two 10.4 m antennas: a third will be added in 1982. The first successful VLBI observation at a wavelength as short as 3.5 mm was carried out between Hat Creek and Owens Valley in 1981.

More powerful arrays under construction are those at Nobeyama (Ishiguro 81 Nobeyama Rad. Obs. Tech. Rep. No.7), consisting of five 10 m dishes (σ = 150 microns) plus the 45 m described above, and that at Plateau de Bure, France, consisting of three 15 m dishes (σ = 50 microns), which is being constructed by IRAM. At 2550 m elevation, the latter will have the best site of all the millimeter arrays. The Nobeyama array will use a 320 MHz bandwidth, 1024 channel by 15 baseline digital Fourier transform correlator of advanced design (Chikada 81 reported at URSI Gen. Assly).

c) Aperture Synthesis Radio Telescopes. (TIFR Centre, Bangalore)

The main developments that have taken place in the triennial period in various countries are summarised below.

Australia - Sadly, the Australian Synthesis Telescope project still is not funded. However, during the period of this report the conversion of the E-W arm of the Molonglo Cross into the Molonglo Observatory Synthesis Telescope (MOST) which employs the fan-beam synthesis principle has been completed and the new instrument has commenced observations (Little 81 reported at URSI Gen. Assly). The telescope operates at a frequency of 843 MHz, with a beamwidth of some 40", and an r.m.s. sensitivity of about 0.5 mJy is achieved in 12 hours.

Developments are in progress on the Culgoora telescope to convert it to a correlator type instrument, with a subsequent increase in speed and flexibility.

The Fleurs Synthesis Telescope is being currently upgraded by the siting of additional 14 m antennae. The final resolution of the telescope should be improved to about 10" at 1415 MHz (Frater et al. 80 Proc. Astron. Soc. Australia 4, 24).

India - The Ooty Synthesis Telescope (OSRT), sited in the state of Tamil Nadu, is now in its final phase of construction. The telescope will eventually consist of ten small cylindrical trough antennae and two 15 m parabolic dishes used together with the existing large Ooty Radio Telescope. The configuration will have a maximum baseline of 9 km E-W by 5 km N-S and operate at a frequency of 327 MHz giving a resolution of 20" x 40" at declination 0°. Observations with the OSRT should begin with a 4 km maximum baseline early in 1982.

At Gauribidanur in the state of Karnataka, the decametric "T" antenna has come into operation during the past two years (Sastry et al. 81 J Astrophys. Astron. 2, 339). The telescope operates as a "Mills Cross" instrument and has a resolution of 26' x 40' sec (δ - 14°) at its current operating frequency of 34.5 MHz. A scanning system automatically cycles the beam rapidly through eight chosen declinations in the range -30° < declination < +60°.

Italy - The 408 MHz "Croce del Nord" radio telescope at Medicina (Ficarra et al. 77 Giornale di Astronomia 3, 115) has continued observations in this period. Initial astronomical results with the extended telescope used in its off-line aperture synthesis mode appeared in 1980 and the first parts of the B3 survey of radio sources are nearing completion.

Netherlands - The Westerbork Synthesis Radio Telescope (WSRT) was used in its temporary "high-density" mode (40 simultaneous interferometers on a 1.5 km E-W baseline) until mid -1979, when two of the four moveable telescopes were transferred to their final positions. Since the spring of 1980, the instrument has operated on a 2.7 km baseline. It is intended to operate the WSRT at an additional frequency around 327 MHz in the near future.

United Kingdom - The Multi Telescope Radio Linked Interferometer (MTRLI) at Jodrell Bank came into operation in its full earth-rotation synthesis mode at the beginning of 1980 (Davies et al. 80 Nature 288, 64). This powerful instrument currently consists of six telescopes at different sites within the West of England and possesses a maximum baseline of 133 km. The system will operate at a variety of wavelengths between λ 73 cm and 1.35 cm giving resolutions between 1" and 0."02, although at the highest frequencies fewer telescopes than the maximum of six are useable. The large N-S component in many of the baselines guarantees a comparable resolution in E-W and N-S, even at low declinations. Observations of nearby calibration sources, of well known position, can be used to determine the phase of an observation in the presence of ionospheric and tropospheric uncertainties, however great success has been achieved using the closure phase relationships between different combinations of the telescopes to produce maps (Cornwell and Wilkinson 81 MN 196, 1067). The telescope is noteable for its high dynamic range mapping where at least 1000:1 has been achieved. Observations of source polarization and spectral lines should soon be available.

At Cambridge the 5 km Telescope has been operated at a frequency of 31.4 GHz giving a resolution of about 0."35 (Scott 81 MN 194, 24p). The efficiencies of the individual 13 m antennae are between 20 and 25% and instrumental phase stability is good.

Observations for the 6C survey of radiosources at 151 MHz have been completed in this period. These possess a resolution of 4' x 4' cosec (δ). The resiting and extension of this array to a maximum baseline of 4.6 km has taken place and initial observations with the revised instrument are underway. A special purpose experiment was made to map the strong radio galaxy Cygnus A at 151 MHz (Winter et al. 80 MN 192, 931). Using a fixed and a portable antenna, interferometer spacings upto 15,674 λ (∿30 km) were observed. As phase stability was not possible due mainly to the ionosphere, in the reduction of the data source symmetry was assumed (a reasonable assumption in the case of Cygnus A) permitting the assignment of phase necessary for image reconstruction. The final resolution of the map was 10" x 16".

U.S.A. - The completion of the construction phase of the VLA (Very Large Array) on the Plains of San Augustin, near Socorro, New Mexico was marked by the dedication of the telescope on October 10, 1980. The completed instrument is described in detail by Thompson et al. (80 ApJ Supl 44, 151). The instrument has since been in regular use for both the quasi instantaneous (snapshot) and full earth-rotation synthesis mapping of astronomical objects. Mapping in spectral line mode is available to users, as well as the observation of total power and polarization characteristics of the continuum emission from radio sources. Since completion, the array has been used in each of its four standard configurations. These have maximum baselines from the phase centre of 21, 6.4, 1.95 and 0.59 km and it is intended to cycle through them over approximately 15 month periods. At present observations can be made in the λ 21 - 18, 6, 2 and 1.3 cm bands and it is planned that a band near λ 92 cm should shortly be available. Among the important developments in map restoration techniques made for use with VLA data, the efficient implimentation of the CLEAN algorithm (Clark 80 AA 89, 377) and the employment of closure phase, or "self calibration", techniques to produce improved quality maps in the presence of amplitude and phase fluctuations (Schwab 80 SPIE Proc. Vol 231; Graham 82 in preparation) can be mentioned. Such developments have permitted the achievement of very high dynamic range mapping.

https://doi.org/10.1017/S0251107X00005046 Published online by Cambridge University Press

The "TPT" decametric array of the Clark Lake Radio Observatory near Borrego Springs, California is now in full operation. Originally the E-W arm was used alone as a fan-beam synthesis telescope (Perley 79 AJ 84, 1443). The final, fully-steerable array is described in Erickson et al. (82 ApJ in press). The array is a "T" of 720 conical spiral antennae (teepee shaped) and has dimensions of 3.0 x 1.8 km. It will operate between 15 and 125 MHz, with best sensitivity in the range 25 to 75 MHz. Both the operating frequency and beam position are adjustable in about 1 msec. A 1024-channel digital correlator has been built and attached to the array. This permits the simultaneous measurement of the complex visibility functions of 512 interferometric baselines between various portions of the array. After Fourier transformation, these visibility data yield a 32 x 32 resolution element picture of the observed area of sky. The frequency dependent angular resolution ranges from 17' to 3', with a sensitivity of about 1 Jy.

U.S.S.R. - The low frequency "T" radio telescope, UTR2, of the Grakovo Radio Astronomy Observatory has continued its survey of radio sources between 10 and 25 MHz (Braude et al. 80 preprint No.147, Kharkov).

Proposed equatorial radio telescope - Among proposed projects for future aperture synthesis telescopes, that concerning the Giant Equatorial Radio Telescope (GERT) perhaps deserves special mention. This design study promotes a scheme that, amongst other objectives, would construct a synthesis telescope consisting of a large cylindrical parabolic trough (size 2 km x 50 m) and fourteen small cylindrical antennae (size 15 m x 50 m). The longest baseline would be 14 km E-W by 12 km N-S, giving a resolution of some 10" at 325 MHz. The project would be a cooperative effort between nations of the developing world and the telescope would be constructed on the terrestial equator. Possible sites are in Indonesia and Kenya. The full proposal is described by Swarup, Odhiambo and Okoye (79 INISSE and GERT: a proposal, Tata Press, Bombay).

d) Very Long Baseline Interferometry (VLBI). (R.S. BOOTH, Jodrell Bank)

The comprehensive review of VLBI by Moffet in the 1979 report of Commission 40 will be taken as a starting point for this report. The past 3 years have seen a consolidation of the situation described by Moffet and the development of the technique to a point where experiments may be conducted by non-specialists.

The major advance in the past 3 years is the implementation of the wideband VLBI system (Coates et al. 75 Tectonphys 29, 9). This, so called Mk III system was developed jointly by NASA (Goddard Space Flight Center), Haystack Observatory, NRAO, and MIT, for application to geodesy and radio astronomy. It is now used regularly in network experiments.

The VLBI networks - Networks of telescopes in the USA and in Europe now operate at regular intervals (8 days every 2 months in the USA and a similar period 4 times a year in Europe) to conduct high resolution observations of radio sources. Both networks are managed by representatives from the participating observatories and have been operated with great success over the past 3 years. Global experiments combining some or all of the telescopes in both networks have also become common. The wavelengths successfully used by the networks have covered most of the RF band from 50 cm to 7 mm.

The US network has now been operational for more than 5 years. Recently compiled statistics by Moran show that more than 200 experiments have been conducted involving about 120 investigators from 33 different institutions. Highlights among the results from the US network in the past 3 years are the hybrid maps by the Caltech group, particularly those of the superluminal source 3C 273 (Pearson et al. 81 Nature 290, 365) and the measurement of proper motions among H_2O maser components (e.g. Genzel et al. 81 ApJ 244, 84).

Operation of the European network on a regular basis began in 1980 although ad hoc experiments have been conducted since 1976. The network is in great demand, its particular attribute being the high sensitivity achieved when Effelsberg, Westerbork and the Jodrell Bank Mk IA telescope are used. A further addition to this network is the Polish 15 m telescope in Torun. A 6 cm receiver is available at Torun and receivers for 18 cm and 21 cm are under development. The Italian group also expect to join the network in 1982 and 30 m antennas are being built at Bologna and in Sicily.

Highlights among the European achievements are the results on the double quasar (Porcas et al. 81 Nature 289, 758) and SS433 (Schilizzi et al. 81 Nature 290, 318).

The Canadian VLBI system has also continued to be used.

In the Soviet Union a narrow band 1.35 cm wavelength VLBI system has been set up between Crimea and Puschino, based on the 22 m telescopes at the Crimea Astrophysical Observatory and the Lebedev Physical Institute (Matveenko et al. 80 Sov Astron Lett 6, 662). Both stations have 70 K maser receivers and Hydrogen maser frequency standards. The 1150 km baseline has been used to resolve several water maser sources.

The Mk III system - This system represents a major increase in sophistication and sensitivity in VLBI. It is a wideband (56 MHz) digital system based on multi-track instrumentation recorders. The data acquisition terminal is computer controlled and takes a broad band IF signal, converts selected frequency windows to video (baseband), separately clips, samples and formats each video signal and records the resulting time-tagged, Mk III serial data streams, in parallel on magnetic tape. The terminal contains the control computer and includes phase and cable calibration among its facilities. (This is especially useful for astrometry and geodesy.)

Twenty eight parallel data streams are recorded simultaneously on magnetic tape at speeds from $\sim$ 17 in/sec to $\sim$ 270 in/sec depending on the bandwidth. With a bandwidth of 56 MHz, each tape lasts for only 20 minutes and this represents something of a problem. Work is continuing in this area to produce stacks of heads with widths as small as 40 microns. The head-stack will be inched across after each pass of tape and multiple pass recording will be adopted. It is hoped that such a modification will increase the total recording time per tape to 3 hours.

Mk III recording terminals are currently available at OVRO, Fort Davis, Haystack, NRAO (140 ft and VLA), Onsala, and Effelsberg, and terminals will be acquired by the Naval Research Labs (Maryland Point), Westerbork, Nobeyama (Japan), Jodrell Bank and Bologna. A 3-station Mk III processor is available at Haystack Observatory and processors are being constructed at JPL/Caltech and MPI, Bonn.

An exciting example of the value of the increased sensitivity provided by the Mk III system is the detection of the predicted 3rd component of the double quasar with a flux density of 1 mJy at 13 cm. (Gorenstein et al. 81 IAU Telegram No.3644).

Other activities - The importance of VLBI has led to several design studies to improve the existing networks. Dedicated arrays of telescopes spaced to adequately fill the u-v plane have been proposed for Canada (Legg (ed.) 1979, NRC report) and for the USA in a Caltech study (Cohen (ed.) 1980 "A Transcontinental Radio Telescope") and a study at NRAO 1981 (The Very Long Baseline Array Design Study). A further design study is underway in Canada.

Representatives of the European community have been conducting an ESA sponsored study of a real time VLBI system based on communication links with a geostationary satellite (LAST) (1981 ESA Report SCI (81) 5). To this end van Ardenne et al.

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(81, NFRA report) have carried out a phase comparison experiment using a 2-way communications link via a satellite. Link precision was found to be better than 10 psec over intervals in the range 10-1000 sec - a better stability than a Rubidium standard. They suggest that a link performance exceeding the capabilities of present hydrogen masers could be achieved. Unfortunately financial limitations will prevent the implementation of this work.

V. RADIO ASTRONOMY INSTRUMENTATION. (N.V.G. SARMA, RRI, Bangalore)

a) Low noise receivers for centimetre and decimetre wavelengths.

GaAs FET amplifiers operating at cryogenic temperatures ($\leq$ 15 K) have now achieved noise performance comparable to that of parametric amplifiers for frequencies upto 15 GHz. Noise temperatures of $\leq$ 10 K at 1.4 GHz and 20 K at 4.5 GHz over a bandwidth of 500 MHz have been reported (Burns 78 NRAO EDIR 197; Vowinkel 80 Electron Lett 16, 730; Williams et al. 80 Microwave Journal 23(10), 73; Weinreb 80 IEEE Trans MTT-28, 1041; Weinreb et al. NRAO EDIR 220). GaAs FET amplifiers are simpler to build and are much more stable compared to paramps. Moreover, simultaneous power and noise match of the input of the FET amplifier obtained by adjustment of the source lead inductance eliminates the need for circulators at the input port. Ibruegger (MPIfR) and Wellington (CSIRO) have reported noise temperatures of about 50 K for cooled GaAs FET amplifiers operating at 10.7 GHz and 15 GHz (NRAO Greenbank Instrumentation Workshop, September 1981).

A reflected-wave maser employing a unique design in which four stages are cascaded via ten circulator junctions and operating at 4.6 K in a three stage closed cycle Helium cryostat achieved a tuning range from 18.3 to 26.6 GHz, net gain of 30 dB and an instantaneous bandwidth of 240 MHz near the band centre. The measured noise temperature of this maser was 13 ± 2 K referred to the room temperature input flange (Moore and Clauss 79 IEEE Trans MTT-27, 249). A travelling wave maser developed in Sweden has a tunable frequency range from 29 to 35 GHz, an instantaneous bandwidth of 60 MHz and an input noise temperature of about 35 K (Kollberg 80 IAU Symp 87, 615).

b) Millimetre wave receivers.

There has been a remarkable progress in Schottky barrier diode mixers for operation beyond 200 GHz. This was made possible by the development of improved GaAs mixer diodes (Linke et al. 78 IEEE Trans MTT-26, 935; Keen et al. 79 Electron Lett 15, 689) and a better understanding of mixer theory (Held and Kerr 78 IEEE Trans MTT-26, 49; Kerr 79 IEEE Trans MTT-27, 938). Room temperature Schottky diode mixers with a quasi-optical local oscillator injection technique have been reported to give good performance upto 670 GHz. Typical mixer noise temperatures (SSB) of 1800 K at 200 GHz, 2600 K at 300 GHz and 12000K at 670 GHz have been achieved (Fetterman et al. 78 Appl Phys Lett 33, 151; Wrixon 78 Conf Digest, European Microwave Conference, 717; Carlson et al. 79 IEEE Trans MTT-26, 706; Erickson 81 IEEE Trans MTT-29, 557). Cooled Schottky diode mixers gave mixer noise temperatures (SSB) around 100 K at 100 GHz (Keen et al. 79 Electron Lett 15, 689; Weinreb and Mattauch 79 Proc Nat Radio Science meeting, URSI, Boulder) and 300 K at 230 GHz (Archer and Mattauch 81 Electron Lett 17, 180).

Super-Schottky diode mixers have also been developed for millimetre wavelengths (McColl et al. 79 IEEE Trans MAG-15, 468) and give a mixer noise temperature around 10 K at 30 GHz.

Millimetre wave mixers using superconductor-insulator-superconductor (SIS) tunnel junctions as mixing elements have been found to give low noise performance with very low local oscillator power of a μW or less (Dolan et al. 79 Appl Phys

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Lett 34, 347). There now exists a quantum mechanical theory (Tucker 79 IEEE J Quan Electron 15, 1234) for these superconducting mixer devices, and it predicts conversion gain and quantum limited noise performance. These predictions have since been qualitatively verified experimentally (Shen et al. 80 Appl Phys Lett 36, 777; Phillips et al. 81 IEEE Trans MAG-17, 684; Rudner et al. 81 J Appl Phys 52, 6366). Mixer noise temperatures of 9 ± 6 K at 36 GHz with a conversion gain of 4 dB, and 60 K at 115 GHz with a conversion loss of 7 dB have been reported. Negative differential output impedence has been observed which can lead to possible infinite available gain (Kerr et al. 81 Physica 108B, 1369) at 115 GHz. At 230 GHz, the best mixer noise temperature achieved so far is around 300 K (Phillips et al. 81 IEEE Trans MAG-17, 684) and this relatively poor performance has been attributed to the inadequate supression of Josephson currents by the applied magnetic field. Single junctions and also arrays of junctions have been tried in the above experiments.

Superheterodyne receivers at 2 mm and 3-4 mm using Josephson mixers as front ends were developed in the USSR (Abljazov et al. 81 Radiotekhnika: Electronica 26, 167; Kislyakov et al. 81 Zh Tech Fiziki 51, 1737). Sensitivities of 0.3 K at 2.2 mm (bandwidth 300 MHz, time constant 1 sec) and 0.03 K at 3-4 mm (bandwidth 30 GHz) were achieved.

Low noise receivers using bulk devices as detector elements have also been developed to operate at short millimetre and submillimetre wavelengths. A bolometer cooled to 0.3 K has been successfully operated at 1.2 mm wavelength (Payne, Green Bank Instrumentation Workshop, September 1981) on the NRAO 36 ft dish at Kitt peak. This gave a minimum detectable temperature of 2 mK for a 1 second integration time. An InSb hetrodyne receiver has been operated at 492 GHz to detect the fine structure transition of atmoic Carbon (Phillips et al. 80 ApJ 238, L103). The receiver noise temperature was about 350 K at 500 GHz. The instantaneous bandwidth is only about 1 MHz and hence the spectra were taken by sweeping the local oscillator. A receiver operating between 460 and 500 GHz using an InSb crystal as the mixing element (Van Vliet 81 Ph.D Thesis, University of Utrecht) with a noise temperature of about 1000 K has been used to detect the CO J = 4 → 3 transition.

At short millimetre and submillimetre wavelengths, generation of sufficient local oscillator power is a problem, and this has been partly solved by the development of Schottky diode multipliers (Schneider and Phillips 81 Int J Infrared mm waves 2, 15; Archer 81 IEEE Trans MTT-29, 552; Erickson 81 IEEE Trans MTT-29, 557). For doublers, efficiencies of 15% have been achieved for the output frequency range of 190 to 230 GHz. For triplers, a peak efficiency of 6% has been achieved for the output frequency range of 200-240 GHz.

Quasi optical components for the short millimeter wavelength range have been developed for such functions as diplexing, beam splitting, band rejecting and focussing (Payne and Wordemen 78 Rev Sci Instrum 48, 1741; Nakajima and Watanabe 81 IEEE Trans MTT-29, 897; Van Vliet 81 Ph.D Thesis, University of Utrecht). These components exhibit lower losses than conventional components.

c) Correlators and Spectrometers.

Wideband autocorrelation spectrometers are now in operation at several observatories. A 256 channel 3-level autocorrelator has been built in South Africa (Woodhouse 80 Trans S African IEE 71, 188). The VLA Correlator consists of 702 wideband digital spectrometers (Review of Radio Science, URSI 81, J2). However, filter bank spectrometers are still the mainstay at millimeter wavelengths. Acousto-optic spectrometers (AOS) are showing great promise to replace the filter banks at millimeter wavelengths and there are several operational AOS systems around the world (Milne and Cole 79 Proc IREE Australia 40, 43; Chikada et al. 80 IAU Symp 87, 625; Mason 80 Proc Soc Photoopt Ind Engrs 231, 291). The

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characteristics of three large bandwidth systems are tabulated below.

Parameter	AOS Model		
	CSIRO	Tokyo	Caltech
Overall Bandwidth: MHz	270	220	100
Resolution: KHz	256	275	160
Number of Channels	1050	1728	1024

Some of the above AOS systems are in regular use on radio telescopes and are reported to give a very nominal degradation of signal to noise ratio compared to conventional filter bank spectrometers.

VI. DATA PROCESSING. (C.R. SUBRAHMANYA, TIFR Centre, Bangalore)

This section deals mainly with some important developments during the past 3 years on the reduction of aperture-synthesis observations. The basic methods of restoration have been reviewed by Bracewell (79 Ann Rev AA 17, 113) and Subrahmanya (80 Bull Astr Soc India 8, 5). The recent emphasis has largely been on implementing proper calibration schemes, taking into account the systematic errors and noise-statistics. This has indeed proved to be highly rewarding as witnessed by the quoted dynamic range of $\sim 10^4$ for a synthesis map of NGC 1275 made at Westerbork (Oort 81 reported at IAU Symp 97). Another striking application of the new techniques can be seen in the maps produced with the multi-telescope radio-linked interferometer (MTRLI) at Jodrell Bank using the hybrid-mapping program CORTEL (CORrecting TELescopes, e.g. Readhead et al. 80 Nature 285, 137). It appears from these results as well as some 'blind-tests' performed by Cornwell and Wilkinson (81 MN 196, 1067) that one can now attempt reliable hybrid-mapping from interferometers with poor amplitude-stability and complete phase-instability. A dynamic range of about 50 seems to be quite feasible even in the absence of phase measurements for the maps of stronger complex sources observed with MTRLI. This is not too far from the typical dynamic ranges attained till a couple of years ago with well-calibrated measurements.

The hybrid mapping technique, originally intended to ensure closure-phase relation has now been extended considerably (e.g. Cornwell and Wilkinson 81 MN 196, 1067; Noordam 81 Proc ESO Conference on "Scientific Importance of High Angular Resolution at Infrared and Optical Wavelengths" Garching). The central theme of the recent techniques is that although the observations with an interferometer give visibilities for each baseline, the number of independent measurements at any given time is no more than the number of individual telescopes used in the system, which therefore should also be the number of constraints imposed on any solution by the measurements. This has been used to correct for instability in the telescope phase or gain and to provide estimates of phases in the absence of phase-calibration. Essentially, one starts with some model to provide an estimate of visibilities which is updated by imposing suitable constraints to provide an antenna-based solution. This is then used to improve the model (usually through CLEAN) and the process repeated till convergence. The method appears to be quite rugged. It is remarkable that, starting from an initial guess of a single point source, CORTEL converges to a realistic solution in about 20 iterations in a completely phase-unstable situation (Cornwell and Wilkinson 81 op cit). The hybrid mapping scheme (self-cal) at VLA uses the first few components of CLEAN to provide an initial guess (Schwab 80 SPIE Proc Vol 231). A similar scheme is used in the Netherlands where the high degree of redundancy provided by the regularly spaced antennas of WSRT is used to achieve a high dynamic range (Noordam 81 op cit).

An efficient scheme has been suggested by Clark (80 AA 89, 377) for implementing CLEAN on computers with limited memory but good computing power through an array processor. The purpose is to save the time normally wasted in accessing the dirty beam from the disk when one is CLEANing a large map.

Imaging from incomplete measurements has been reviewed in the context of several subjects in the book edited by Herman (79, "Image Reconstruction from Projections: Implementation and Applications", Springer Verlag, New York). The book also includes a chapter by Bracewell on the problem in radio astronomy.

There has been a continued effort in demonstrating the improvement in restoration provided by use of prior knowledge like positivity and sharpness/smoothness of images. Typical examples of methods for implementing prior knowledge explicitly can be found in the "Optimum Deconvolution Method" (Subrahmanya 80 AA 94, 85) and in a scheme using Simplex method (Baker 81 AA 94, 85). Maximum entropy method (MEM) has been extended by Bryan and Skilling (80 MN 191, 69) to noisy situations by forcing the residuals to have the known statistics of noise. They have shown that this results in an improved restoration.

There is a growing belief that one should not attach too much significance to "entropy" in MEM but look upon MEM as one of the ways of ensuring consistency with measurements and prior knowledge like positivity. It appears that a wide variety of functions satisfying some general mathematical requirements can efficiently play the role of "entropy" in MEM (Nityananda and Narayan, RRI Bangalore, in preparation).

As the attempts towards phaseless reconstruction, super-resolution and exceptionally high dynamic ranges are becoming more and more common, it is now very important to examine the question of reliability more thoroughly. The existing simulations or "blind tests" are perhaps too simplistic to lead to specific conclusions on reliability to the accuracy demanded by recent developments. A measure of reliability based on properties of the residuals and the derived solution will be of great value.

Mention should also be made of the standardization of a format "FITS" (Flexible Image Transport System) for the interchange of astronomical images and other digital arrays on magnetic tape (Wells et al. 81 AA Suppl 44, 363; Greisen and Harten 81 AA Suppl 44, 371). It provides a simple and powerful mechanism to generate self-documenting data tapes for the unambiguous transmission of n-dimensional, regularly spaced data arrays.

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President of the Commission

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