40. RADIO ASTRONOMY (RADIO ASTRONOMIE)

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INSTRUMENTATION

Aperture Synthesis Radio Telescopes - Vigorous progress has continued in this field over the last three years with proposals for new telescopes, first operations of those under construction and enhancements of existing telescopes.

In Japan the Nobeyama interferometer comprising five 10m antennas is now operational at 1.3 cm and it is planned to start observations near 3 mm soon.

Construction of the Australia Telescope is well advanced with the rail track and the first of the six 22 m antennas on a 6 km baseline completed whilst the other antennas are under construction. Tests on the first interferometer are planned for the end of 1987 with completion of the array in 1988. Initial operation is expected to cover four frequency bands between 1.4 and 10 GHz.

The three-antenna IRAM interferometer for mm wavelengths is under construction in southern France. The first of the 15 m carbon-fibre antennas is now completed and under test.

In the United States notable progress has been made on the Very Long Baseline Array (VLBA) with the completion of construction of the first of the ten 25-m antennas at a site close to the VLA in New Mexico. It is hoped that the array will be completed in 1992.

The proposal for a Giant Metre-Wavelength Radio Telescope (GMRT) in India has been approved and a site near Pune adopted. The array will comprise 34 45 m fully steerable paraboloids, 16 being concentrated in a 1 km central array and the remaining 18 being distributed along arms of a Y-shaped array with each arm extending to about 14 km. The design includes operation in five frequency bands between 38 and 610 MHz and completion is planned for 1992.

Significant improvments to existing arrays include:- the addition of a third 10.4 m antenna to the Berkley mm array at Hat Creek; the operation of the VLA at 327 MHz and trials on four of the antennas at 75 MHz; operation of the MERLIN array at 151 MHz and extension of the array by the inclusion of an existing 18 m antenna at Cambridge; conversion of the Cambridge 5 km telescope to cooled broad-band operation for microwave background work and operation of the low frequency synthesis telescope at 38 MHz.

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Single Dish antennas - The principal developments in this field have been for mm and submm antennas.

The IRAM 30 m antenna sited near Granada in Spain has been in full operation during the last three years, with full efficiency at 2 mm wavelength.

The UK-Netherlands James Clerk Maxwell Telescope (JCMT), a 15 m antenna for mm and submm wavelengths, sited on Mauna Kea, Hawaii, has been completed in 1987 and first operations at 1.3 mm have started. Full efficiency at 0.8 mm is expected after further surface adjustment following current holographic tests.

The 10.4 m Cal-Tech antenna, also sited on Mauna Kea, has been commissioned in 1987 and is in operation at mm and submm wavelengths.

Another 10.4 m antenna, based on the same design, has been completed at Bangalore, India and has been in operation since 1985. A Swedish-European 15 m antenna using the design for the IRAM dishes has been built in Chile and is now in operation, although not yet at the shortest wavelengths.

Imaging Techniques - The last triennium has seen continued improvement in the imaging performance of radio-telescopes, due largely to research in algorithms for image processing.

The CLEAN algorithm for image deconvolution has been investigated critically by Tan (1986, MNRAS, 220, 971-1001), particularly with respect to the well-known instability which produces corrugations on extended structure. A now widely-used variant of CLEAN (Steer et al., 1984, A & A, 137, 159-165) avoids the instability and also provides much faster reconstruction of extended emission.

The Maximum Entropy method of image deconvolution is becoming more popular, mainly because of its flexibility in handling different types of data, and its speed advantages over CLEAN when processing very extended objects. The properties of MEM solutions are better-understood than those of CLEAN solutions, mainly because the former are defined by a condition rather than as the end result of a sequence of very non-linear operations as in CLEAN. Narayan and Nityananda (1986, Ann. Rev. Astron. & Astrophys., 24, 127-170) have reviewed MEM in image reconstruction ably and comprehensively. Recent work has focused on algorithms (e.g. Wilczek and Drapatz, 1985, A & A, 124, 9-12, Cornwell and Evans, 1985, A & A, 143, 77-83, Reiter and Pfleiderer, 1986, A & A, 166, 381-392) rather than philosophy. Cornwell (1984, NRAO mm array memo 34) has used MEM for the imaging of very large objects by interferometric arrays.

Braun and Walterbos (1985, A & A, 143, 307-312) developed a simple method for estimating the short-spacings, around about a dish diameter, which are normally inaccessible to interferometric arrays. Conway (see Wilkinson et al, 1986, Proc. IAU symp. on VLBI, Boston) has developed a technique of "Multi-frequency Synthesis" in which the u, v plane is filled in by observing at a number of frequencies and spectral effects are implicity corrected in the deconvolution step. This will allow VLBI imaging of sources of more complexity than previously possible.

Recent developments in methods for obtaining good phase information from interferometers are mainly refinements of the now widely-accepted self-calibration/closure phase techniques (see e.g. Pearson and Readhead, 1984, Ann. Rev. Astron. & Astrophys., 22, 97-130). Linfield (1986, A.J., 92, 213-218) has described a difficulty in applying these techniques to arrays with poorly mixed spacings. Cornwell (1987, A & A 180, 269-274) has shown that the speckle-masking technique, which is used in high-resolution imaging at optical wavelengths, relies upon closure phase, and also that it can be adapted to radio-interferometry to allow imaging of weaker objects than previously possible. Cornwell and Napier (1986, Proc. NRAO workshop on "Radio Astronomy in Space") have shown how, with the aid of a correlating focal plane array, self-calibration may be applied to single-aperture observations to remove the effects of aberrations.

Finally, as a sign that imaging techniques developed in radio astronomy are spreading, aperture synthesis imaging has been demonstrated at optical wavelengths by Haniff et al., (1987, Nature, 328, 694-696). By measuring true amplitudes and closure phases with a simple, rotatable linear mask in a conventional optical telescope, they were able to image a simple binary at high-resolution (about 50 milliarcsecond) with low-light levels.

SOLAR SYSTEM RESEARCH

The Sun - Microwave Images of solar active regions and flares obtained with the VLA (Kundu and Lang, 1985, Science, 228, 9) and WRST (Alissandrakis and Kundu, 1984, A & A 271, 39), were used to study the preflare build-up (Kundu et al., 1985, Ap. J. Suppl. 57, 621) and magnetic field topology in the vicinity of flaring regions. It seems that the appearance of new flux, which interacts with pre-existing regions to form neutral or current sheets is essential to trigger the onset of a flare (Kundu and Shevgaonkar, 1985, Ap. J., 291, 860; Kundu, 1986, Adv. Sp. Res. 6, 93). Observational evidence for magnetic reconnection in microwave bursts was obtained from VLA images of a flare (Kundu 1985, Proc. IAU Symp. No. 107, p. 185). Three-dimensional structures of active regions were obtained using the VLA at 2, 6 and 20 cm wavelengths (Shevgaonkar and Kundu, 1984, Ap. J., 283, 413). The 2 cm radiation is mostly thermal bremsstrahlung from loop foot points, while 6 and 20 cm radiation is dominated by low-harmonic gyroresonance radiation from the upper part of the loop.

Simultaneous observations with the VLA at 2 and 6 cm of a flare showed different locations of 2 cm (foot points) and 6 cm (loop top) sources, and time differences in the peak times (Shevgaonkar and Kundu 1985, Ap. J. 292, 733). Using a DC electric field flare model, this delay in the peak times was interpreted and the strength of the electric field in the flaring region was estimated to be 0.2-4 μ stat volt cm^{-1}. Detailed computations have been made of the microwave structure of hot coronal loops and compared with VLA and WSRT observations (Holman and Kundu 1985, Ap. J. 292, 291).

Interpreting solar active region emission at centimeter wavelengths as gyroresonance radiation, Westerbork and VLA images have been used to estimate coronal magnetic fields (Alissandrakis and Kundu, 1984, A & A, 139, 271; Gary and Hurford, 1987, Ap. J., 317, 522). Using a new method of analysis and identifying certain features on the radio maps, both the vertical and horizontal components of the sunspot magnetic field have been mapped at specific locations in the low corona.

VLA images of the quiet sun have been made at 20 and 6 cm with particular emphasis on coronal bright points (Habbal et al., 1986, 306, 740; Fu et al., 1987, Solar Phys. 108, 99) and filaments (Kundu et al., 1986 A & A, 167, 166; Gary, 1986, NASA Publ. No. 2442, p.121). Coronal bright points appear to fluctuate in intensity over time scales of a few minutes, similar to what is observed in EUV. Filament observations show good correspondence between 20 cm temperature depressions and large coronal cavities as observed in He spectroheliograms.

Meter-decameter wavelength imaging observations have been made with the Clark Lake and Nancay radioheliographs (Kundu 1986, Highlights in Astronomy, 7, 725, Lantos and Alissandrakis, 1986, Highlights in Astronomy, 7, 761). In particular the Clark Lake instrument has been used as a radio coronagraph for studies of coronal streamers and coronal holes (Kundu et al., 1986, Solar Phys. 108, 113; Gopalswampy et al., 1986, Solar Phys. 108, 333). Type III burst emitting electrons propagate in dense coronal streamers, and coronal holes at lower frequencies (50 and 38.5 MHz) are radially displaced relative to their higher frequency locations and chromospheric positions as determined from He spectroheliograms. The discrepancy that exists in electron density values as determined from radio and UV data has not been resolved. Microbursts which are low brightness temperature type III-like bursts have been discovered with the Clark Lake radioheliograph (Kundu et al., 1986, Ap. J. 308, 436). The observations imply that energy releases on the Sun continue to be impulsive with nonthermal electron distributions, for small releases of energy, similar to the hard X-ray microbursts. They seem to be produced by plasma emission process at the fundamental plasma frequency (White et al., 1986, Solar Phys. 107, 135). Raoult et al., (1985, Astrophys. J., 299, 1027) showed that in the flare preflash phase type III and type V bursts occur, characteristic of events associated with high energy electron acceleration mechanisms.

On the theoretical side, type IV bursts have been explained as due to harmonic plasma radiation (Gary et al., 1985, A & A, 152, 42). Electron-cyclotron maser stability has also been proposed as the source of type IV bursts at decimeter and longer wavelengths, specifically to Zebra-stripes and continuum bursts as well as type IV continuum bursts (Winglee and Dulk 1986, Ap. J. 307, 808, and 310, 432).

Planets, Satellites, Comets Asteroids - Largely because of the general interest in Halley's Comet, studies of comets have dominated solar system radio astronomy during the past triennium. Collected results appear in two symposium volumes: "Exploration of Halley's Comet" - 20th Eslab symposium (ESA report SP250) and "Cometary Radio Astronomy" - proceedings of an NRAO workshop, September 1986. Continuum measurements have resulted in detection of Halley's comet (Altenhof et al., Astron. Astrophys., 164, 227, 1986) and indications of possible effects of plasma in the tail of Comet Austin 1982g during occultation of a radio source (de Pater and Ip, Ap. J., 283, 895, 1984). Spectroscopy has provided much new information about molecular production in these objects. Highlights include the unambiguous detection of HCN in Halley's comet (Despois et al., Astron. Astrophys., 160, L11, 1986; Schloerb et al., Ap. J. Lett., 310, L55, 1986; Winnberg et al., Astron. Astrophys, 172, 335, 1987) and a number of detailed studies of OH. The pre-Halley OH-observations of 16 comets are summarized by Snyder (AJ, 91, 163, 1986). The first radio image of a comet was made in OH by de Pater et al., (Ap. J. Lett., 304, L33, 1986). The emission is concentrated in clumps surrounding a hole which maybe the first direct observation of OH maser quenching in the inner cometary coma. Five comets have now been detected by radar (summarized by Ostro, Encyclopedia of Science and Technology, 10, 611, 1987) including Halley by the Arecibo group (Harmon et al., in preparation).

With the detection of Pluto at mm wavelengths by the 30-meter telescope at Pico Veleta, thermal disk emission has now been recorded from all nine official planets. Other work on the planets has included the first radio resolution of the disk of Mercury using the VLA at a wavelength of 6 cm (Burns, et al., Nature, Oct. 1987) and studies of the surface temperature of Mars where a surface anomaly appears to be present between about 10° and 40° south latitude (Rudy, Ph.D. thesis, Caltech 1987). CO in the atmosphere of Venus is being studied by teams of observers using both the Hat Creek and OVRO millimeter arrays.

Data on Saturn and its rings at wavelengths ranging from 2.7 mm (Dowling, et al., Icarus, 70, 506, 1987) to 20 cm now exist at all inclination angles of the rings from edge-on to the maximum tilt of 26°. A Grossman (Caltech) is analyzing

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all the VLA data to derive dielectric and other properties of the ring particles plus the filling factors in the rings. In an interesting experiment to obtain both spatial and Doppler resolution, R. Goldstein, et al., have transmitted an 8 GHz radar signal from the Goldstone antenna and received it in the line mode with the VLA. The results of this powerful technique look very promising.

The first observation of the zone-belt structure in Jupiter's atmosphere was reported by de Pater and Dickel (Ap. J., 308, 459, 1986). de Pater (Icarus, 68, 344, 1986) analyzed these data at 1.3, 2, and 6 cm to conclude that there is a significant depletion of ammonia in the Jovian belts at altitudes above a level where the pressure is about 2 atmospheres. Below that, ammonia is overabundant relative to the solar value in both zones and belts. Jupiter's radiation belts continue to be monitored at 1.4 GHz by de Pater for correlation with other solar-system phenomena. Radio astrometry of the Jovian satellites has indicated an error of 475 km in the relative positions around the orbits of Callisto and Ganymede (Muhleman et al., AJ, 92, 1428, 1986).

The Planetary Radio Astronomy experiment on the Voyager 2 spacecraft performed with full reliability during the Uranus encounter in January 1986. By analysis of the decametric radiation, Warwick el al., (Science, 233, 102, 1986) have determined a rotation period of 17.24 hours for the dipolar magnetic axis of that planet which is tilted 60° from the rotational axis.

Observations of asteroids with the VLA at 2-cm have now provided data on at least one asteroid in each of the C, S, and U optical classifications (Webster et al., Icarus, 60, 538, 1984 and 69, 29, 1987). They all appear to be covered with a thin layer of impact-hardened material.

GALACTIC RESEARCH

Surveys - The second part of an absolutely calibrated 1.42 GHz survey of the entire northern sky has been published (Reich and Reich, 86 AA Sup. 63, 205). These observations with 35' angular resolution cover the area $24° \gtrsim \delta \gtrsim 19°$. Jonas et al., (85 AA Sup. 62,105) have mapped the area $12^h \lesssim \alpha \lesssim 22^h$, $-63° \lesssim \delta \lesssim -24°$ of the southern sky at 2.3 GHz with 20' angular resolution. An analysis of these data has been made by Jonas (86 MN 219,1) reporting new loops, spurs and arcs with angular dimensions between 2° and 6°.

Sensitive observations of the Galactic plane at 2.7 GHz have been made by Reich et al., (84 AA Sup. 58, 197). Total intensity maps with 4.3' angular resolution are presented for the region $357.4° \lesssim l \lesssim 76°$ and $-1.5° \lesssim b \lesssim 1.5°$. In addition, a catalogue lists the data for 1212 small diameter sources. Maps showing the linear polarized emission obtained from the same observations have been published by Junkes et al., (86 AA Sup. 69,451). The Cygnus region has been mapped at 4.8 GHz with 2.6' angular resolution by Wendker (84 AA Sup. 58, 291). Sofue et al., (84 PASJ 36, 297) discussed a first section $(21° \lesssim l \lesssim 26°)$ of a 10 GHz survey of the Galactic plane with 2.7' angular resolution. The Galactic plane has been surveyed with 0.5' angular resolution at submillimeter wavelength (0.7-2 mm) between 0° and 30° longitude by Pajot et al., (86 AA 154, 55). Results of decameter observations at four wavelengths covering the Galactic plane between 147° and 153° longitude have been discussed by Abramenkow (85 AZh 62, 1057; Sov Ast 29, 616).

A source survey covering the northern sky between $-5° \lesssim \delta \lesssim 82°$ at 1.4 GHz was carried out by Condon and Broderick (85 AJ 90, 2540; 1986 AJ 91, 1051). The maps have 12.7'x11.1' angular resolution and contain also Galactic structures with an extent of less than 1° in declination. About 3 10^3 sources per sr stronger than 0.15 Jy are contained in the maps. The RATAN-600 radio telescope has been used at various wavelengths between 2 cm and 31 cm to catalogue and to investigate Galactic radio sources in the centre and anticentre area (Pyantunina, 85 AZh 62, 218; Sov Ast 29, 125; Gosachinskii, 85 AZh 62, 226; Sov Ast 29, 128; Berlin et al., 85 AZh 62, 229; Sov Ast 29, 130; Aliakberov et al., 85 AZh 62, 482; Sov Ast 29, 281). Fich (86 AJ 92, 787) has made a complete high resolution survey at 6 cm of sources with an extent less than 2' and a flux density larger than 0.3 Jy at 21 cm wavelength in the area $93° \lesssim l \lesssim 163°$, $-4° \lesssim B \lesssim 4°$. The sources are either HII-regions or of extragalactic origin. No compact supernova remnant could be identified. High resolution observations of 44 compact radio sources located in the Galactic plane have been made by Green (85 MN 216, 691) in a search for young but distant supernova remnants. Most of the sources seem to be extragalactic. Repeated 6 cm observations of discrete sources in the Galactic plane were done by Geregory and Taylor (86 AJ 92, 371) to detect and to study variable sources. From their list of 1274 sources, which is estimated to be complete down to 70 mJy, they find 32 variable sources and 27 sources which are possible variable.

Radio Stars - The high sensitivity and resolving power of the VLA has been used increasingly to study radio emission from a variety of stellar classes.

Multi-wavelength radio observations of red dwarf (dM_e) flare stars (cf. Kundu and Shevgaonkar 85 ApJ 297, 644) can be interpreted as indicating that the quiescent flux is non-thermal gyrosynchrotron radiation, but the narrow-band structure of the slowly varying decimetric emission reported for YZ CMi (Lang and Willson 86 ApJL 302, L 17) may also require a coherent radiation mechanism. Some coherent emission process is favoured for radio flares of red dwarfs: a) 20 cm flaring from AD Leo and L726-8A exhibited narrow-band differences (White et al. 86 ApJ 311, 814); b) radio bursts from AD Leo contained ms "spikes" which are up to 100% circularly polarized and have $T_B \gtrsim 10^{16}$ K at 1.4 GHz (Lang and Willson 86 ApJ 305, 363); c) the first dynamic specra of stellar microwave flares from UV Cet = L726-8B showed distinct variations with frequency (Bastian and Bookbinder 87 Nature 326, 678).

Important advances have been made in the study of a variety of radio-emitting pre-main-sequence (PMS) stars. A luminosity-limited 6 cm survey of the Tau-Aur dark clouds (Bieging et al. 84 ApJ 282, 699) indicated that, by the time a PMS star is visible as a T Tau variable, detectable continuum emission (either free-free from an ionized stellar wind or non-thermal radiation) is rarely found. However, the PMS star DoAr21 in the ρ Oph star-formation cloud was found to exhibit strong, extremely variable radio flaring (Feigelson and Montmerle 85 ApJL 289, L19). This added credence to the idea that at least some PMS stars exhibit high degrees of atmospheric magnetic activity. More recent work by Kutner et al. (86 AJ 92, 895) and by Cohen and Bieging (86 AJ 92, 1396) on the radio variability of some PMS stars has strengthened this conclusion.

Understanding of the radio emission of symbiotic stars has improved following the VLA survey by Seaquist et al. (84 ApJ 284, 202) and a binary model (Taylor and Seaquist 84 ApJ 286, 263) in which the radio flux arises form the portion of the stellar wind of the cool, mass-losing star that is photoionized by the hot companion. Observations of the symbiotic star CH Cyg by Taylor et al. (86 Nature 319, 38) have revealed a strong radio outburst and the production of a multi-component radio jet (cf. R. Aqr?) expanding at the rate of 1.1 arcsec/yr. This has been interpreted as the result of accretion at, or near, the Eddington limit from the M7III star onto a white dwarf companion.

In 1985 the first radio detection of a recurrent nova was made by Padin et al. (85 Nature 315, 306) only 18 days after the optical outburst. Subsequently, an extensive series of multifrequency VLA observations (Hjellming et al. 86 ApJL 305, L71) has revealed complex decay of the radio emission which is probably

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non-thermal.

The radio emission of Wolf-Rayet stars has been carefully studied by Abbott et al. (86 ApJ 303, 239,). Most are thermal wind sources but some are non-thermal emitters. Non-thermal radio emission, which is much less common in W-R stars than in luminous OB stars, is most plausibly explained as synchrotron emission from electrons accelerated to relativistic energies by the strong shocks that permeate the chaotic stellar winds close to the star (White 85 ApJ 289, 698). In this model non thermally emitting OB stars (e.g. Abbott et al. 84 ApJ 280, 671; Persi et al. 85 AA 142, 263) would possess much larger ratios of rotational to shock velocities and/or stronger magnetic fields than W-R stars.

Results on radio flaring from Cyg X-3 are given by Molar et al. (84 Nature 310, 662), Johnston et al. (86 ApJ 309, 707) and Spencer et al. (86 ApJ 309, 694). A 5-year study of ScoX-1 (Geldzahler and Fomalont 86 ApJ 311, 805) has shown that all 3 radio components are approximately co-moving with the optical binary and are thus associated with it. Radio detections of galactic-bulge X-ray sources have been made by Grindlay and seaquist (86 ApJ 310, 172).

Valuable surveys of RSCVn and RSCVn-like stars have been made by Mutel and Lestrade (85 AJ 90, 493), Drake et al. (86 AJ 91, 1229) and Mutel et al. (87 AJ 93 1220). Useful results for individual stars were given by Innis et al. (85 ProcASA 6, 160). Simon et al. 85 ApJ 295, 153), Little-Maranin et al. (86 ApJ 303, 780) and Bunton et al. (86 ProcASA 6, 316).

Results of a survey of cool giants and supergiants were given by Drake and Linsky (86 AJ 91, 602). Variable radio emission from the 4 Dra system (M3 III + cataclysmic binary) was detected by Brown (87 ApJL 312, L51). The first radio detection of a conventional Be star was made by Taylor et al. (87 MN, 228, 811).

Dual polarisation VLVI observations enabled the milliarcsec radio structures of 7 stellar binaries to be determined (Mutel et al., 85 ApJ 289, 262). Stellar radio astrometry has been actively pursued by Johnston et al. (85 AJ 90, 1343 and 2390).

The theory of long-wavelength radiation from isothermal stellar winds has been reformulated as a useful curve of growth method by Lamera and Waters (84 AA 136, 37). Finally, Wendker has done the field a good service by bringing out a new edition of his catalogue of stars with radio continuum emission (87 AA Suppl. Ser 69, 87).

Pulsars - The discovery of the millisecond pulsar PSR 1937+21 and uncertainty over the evolution of young pulsars has led to several surveys with good sensitivity to pulsars with short period. Two new millisecond pulsars have been discovered. Segelstein et al., (86 IAUC 4162) used Arecibo in discovering PSR 1855+09, a binary pulsar with a period of 5.4 ms. Lyne et al., (87 Nature 328, 399) used the Jodrell Bank antenna to discover PSR 1821-24 with period 3.1 ms in the core of the globular cluster M28. This followed a two year trail of investigation (Hamilton et al., 85 AJ 90, 606; Mahoney & Erickson 85 Nature 317, 154; Erickson et al., 87 ApJ, 314, L45). Both discoveries give strong support for the accretion spin-up mechanism for millisecond pulsars (Srinvasan & Radhakrishnan 84 Proc. 2nd Asian Pac. Reg. Meeting on Astronomy, Bandung, Eds. Hidayat and Feast, 423).

440 pulsars are now known. 100 have been discovered in the past 3 years in major surveys (Dewey et al., 85 ApJ 294, L25; Stokes et al., 86 ApJ 311, 694; Clifton & Lyne 86 Nature 320, 43). Few of the new pulsars have periods less than 100 ms. Clifton & Lyne at 1400 MHz overcame galactic background noise and interstellar scattering and detected 40 new pulsars towards the inner galaxy in

only 200 square degrees. Three new pulsars have been discovered in binary systems, making a total of seven: the millisecond pulsar PSR 1855+09, PSR 1831-00 (Dewey et al., 86 Nature 322, 712) and PSR 2303+46 (Stokes et al,m 85 ApJ 294, L21). Van den Heuvel (84 JAA, 5, 209) has reviewed binary evolution scenarios. Kulkarni (86 ApJ 306, L85) has identified the companions of PSR 0655+64 and PSR 0820+02 as white dwarfs. The low white dwarf temperature suggests great age for PSR 0655+64 but the magnetic field has not decayed accordingly.

Lyne et al. (85 MNRAS 213, 613) have summarised current understanding of the galactic distribution and evolution of normal pulsars. The small number of short period pulsars have led Chevalier & Emmering (86 ApJ 304, 140) and Narayan 87 IAU Symp 125, 67) to make cases for pulsar birth at long period.

Gwinn et al. (86 AJ 91, 338) have used VLBI to measure the annual parallaxes of PSR 0950+08 and PSR 0823+26.

Davis et al. (85 Nature 315, 547) have shown that PSR 1937+21 is comparable in stability to the best man-made atomic clocks. They demonstrate its value as a possible gravitational wave detector. A value of braking index $n = 2.83 \pm 0.03$ has been obtained for PSR 1509-58, only the second so far measured (Manchester et al., 85 Nature 313, 374). One small and one massive glitch have occurred in the relatively old pulsar PSR 0355+54 (Lyne 87 Nature 326, 569). In a monitoring program in Hartebeesthoek, Flanagan observed a glitch in the Vela pulsar in July 1985 (87 IAU Symp 125, 64). Crab pulsar monitoring continues at Jodrell Bank. Backer & Hellings (86 Ann Rev. AA. 24, 537) have summarised the use of pulsar timing observations and General Relativity. Pines & Alpar (85 Nature 316, 27) have reviewed superfluidity in NS.

Hankins and Rickett (86 ApJ 311, 684) have measured the frequency dependence of the profiles of 12 pulsars, showing spectral differences between core and conal emission. Rankin (86 ApJ 301, 901) shows how single pulse properties differ between core and cone. Valuable single pulse polarisation studies have been made by Stinebring et al., (84 ApJ Supp 55, 247 and 279). Remarkable subpulse drifting through the whole of the period has been observed in PSR 0826-34 (Biggs et al., 85 MNRAS 215, 281.

Rickett et al. (84 AA 134, 390) recognised that the long term, intensity variations of pulsars are due to refractive effects in the interstellar medium. Refractive effects were observed by Hewish et al., (85 MNRAS 213, 167), Smith & Wright (85 MNRAS 214, 97) and Cordes & Wolszczan (86 ApJ 307, L27). Theoretical discussion was provided by Blandford & Narayan (85 MNRAS 213, 591), Romani et al., (86 MNRAS 220, 19) and Cordes et al. (86 ApJ 310, 737). Cordes (86 ApJ 311, 183) estimated the speeds of 71 pulsars using ISS data. Lyne & Hamilton (87 MNRAS 224, 1073) have determined the rotation measures or 163 pulsars.

Many observational and theoretical aspects of pulsars were reviewed at IAU Symposium 125 on the Origin and Evolution of Neutron Stars (87 Eds Helfand & Huang) and at the Nato ASI on High Energy Phenomena Around Collapsed Stars (86 Ed Pacini). Taylor & Stinebring (86 Ann Rev AA 24, 285) have reviewed recent progress in the understanding of pulsars.

<u>Supernovae (SN) and Supernova Remnants (SNR)</u> - SN 1987A in the LMC has provided the first opportunity for radio observations to be made soon after a SN outburst. A weak but immediate burst of emission with a time scale of a few days was detected at several Australian observatories (87 Nature 327, 38). Early VLBI observations apparently resolved the SN which is consistent with the initial expansion velocity measured optically. A review of radio SN in more distant galaxies (86 ApJ 301, 790) includes detailed light curves for two Type II events.

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Radio emission was detected only after some months as it rose rapidly to a peak around a thousand times more luminous than for SN 1987A to date. Reduced absorption in the circumstellar material as the region of non-thermal emission expands can explain this behaviour. The weakness and promptness of the radio burst for SN 1987A may be due to a low circumstellar density in the immediate vicinity of its blue progenitor. It could remain radio quiet for decades until either it interacts with the surrounding medium or a central pulsar is revealed.

More than 40 radio sources have been detected within 300 pc of the nucleus of M82 (85 ApJ 291, 693). Most are presumed to be radio supernovae or remnants but are more luminous than comparable objects in the Magellanic Clouds. They may be due to a recent burst of star formation deep within giant molecular clouds. VLBI observations of expanding remnants may be be used for the determination of extragalactic distances (85 SN as distance indic. pp 107, 123, 130).

Radio properties of SNRs are described in general reviews (84 Ann Rev Astron Astrophys 22, 75; 84 Ap Sp Sci 3, 35). Statistical studies and Σ-D relations are discussed in 85 ApJ Lett 295, L13; 86 AA 166, 257 and 86 Astrophys 24, 232.

Most work continues to be on individual SNRs in the Galaxy. A comprehensive review by Caswell will appear in the proceedings of IAU Colloquium 101 'Interaction of SNRs with the Interstellar Medium'. A few newly identified remnants have been reported but studies have concentrated on the structure of known remnants. Maps with high resolution and sensitivity obtained from the VLA and Westerbork telescopes combined with information from other wavelengths have permitted detailed investigation of interactions with circumstellar and interstellar material. At lower resolution the Molonglo (MOST) and Penticton (DRAO) telescopes have provided maps with a wide field of view.

All types of SNR morphology have received attention - shells, centrally concentrated Crab-like plerions, shell-plerion combinations and unusual morphologies where special circumstances may enhance a particular property. The classification of some non-thermal galactic objects as SNRs has been questioned (85 Nat 313, 115; 314, 720; MNRAS 225, 329).

The broad structure of many remnants has been interpreted as due to 'barrels' - regions with axial symmetry and only weak radiation from the end caps (Kesteven and Caswell, 87 AA in press) or as double loops (87 AA 171, 205). Distinctive features in individual remnants include jets (85 Nature 316, 44; Kesteven et al., IAU Symp. 125), markedly different expansion on opposite sides (87 ApJ 315, 580) and expansion into pre-existing interconnected spherical shells (86 MNRAS 221, 809; 86 AA 164, 193).

The last reference deals with IC 443 which is also the subject of other studies (85 ApJ 290, 596; 86 MNRAS 221, 473; 86 AJ 92, 1349; 87 AA 173, 337). Detailed maps of other well known objects have been used for measurements of expansion and interactions with the surrounding medium:-
the Cygnus Loop (84 MNRAS 211, 433; 85 AA 148, 52; 86 ApJ 306, 266); SN 1006 (86 AJ 92, 1138); Tycho (85 MNRAS 216, 949); Kepler (84 ApJ 287, 295); Cas A (86 MNRAS 219, 13; 87 Nature 327, 395); CTB 80 (84 AA 139, 43; 85 AA 145, 50) and the Crab Nubula (85 MNRAS 212, 359; 86 Sov Astron Lett 12, 112).

Observations of the emission and absorption of radio spectral lines associated with SNRs are valuable for estimating distances and studying interactions. Some results are contained in the references above; others are reported in 86 AA Supp 63, 345; 86 MNRAS 219, 427; 86 MNRAS 221, 809.

The increasing use of mm wavelengths is expected. There are recent reports of continuum observations of Cas A and the Crab Nebula (86 ApJ 298, 644; 86 AA

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167, 145) and spectral line measurements (86 ApJ 309, 667; 87 AA 173, 337). Another forthcoming development is the completion in 1988 of the Australia (radio synthesis) Telescope which will permit improved mapping of southern objects in the Galaxy and the Magellanic Clouds.

Galactic Center - An important new result has been the first direct determination *with VLBI of the distance to the galactic center molecular cloud Sgr B2 from the* proper motions of a cluster of H_2O maser spots (Reid et al., 87, IAU Symp. 115: Star Forming Regions, ed. Peimbert). The derived distance is 7.1±1.5 kpc, where the uncertainlty is dominated by the number of maser features measured. Sgr B2 is almost certainly within a few hundred parsec of the galactic center.

Investigations at high spatial resolution (VLA, 100 m telescope, 45 m Nobeyama telescope) of the central $\approx 10^2$ pc region of the Galaxy have given evidence for large scale, poloidal magnetic field structures. Nonthermal filaments in the radio "arc" ($l^{II} \approx 0.1°$) stretch 40 pc above and below the galactic plane and show extended, highly polarized plumes at their ends (Tsuboi et al., 85, Publ. Astr. Soc. Japan 37, 359; Seiradakis et al., 85, Nature 317, 697; Yusef-Zadeh 86, Ph.D. Thesis University Columbia). Various explanations of the phenomena have been proposed, typically based on gas which is accelerated along the field lines and away from the center and the galactic plane. Faint threads of 30 pc length and ≈0.3 pc width near Sgr A have been interpreted as magnetic flux tubes or, in a more speculative vein, as superconducting cosmic strings (Morris and Yusef-Zadeh 86, BAAS 18, 1023). Thermal radio emission in the curved filaments of the "arc" now appear to be the photoionized edges and surfaces of dense, tidally disrupted molecular clouds which may fall toward the center (Yusef-Zadeh et al., 87, AIP Conf. 155: "The Galactic Center", ed. Backer; Güsten et al., 87b, AA, in press). A high quality, well sampled survey at ≈100" resolution of the molecular gas in the galactic center region has become available from work at the Bell Labs' 7 m telescope (Bally et al., 87a ApJ Sup. 65,; 87b ApJ, in press), giving detailed information on distribution, density structure, mass and kinematics of molecular clouds near the galactic center. These and other observations show that the molecular clouds in the central few hundred parsec are denser and warmer than clouds in the disk, possibly due to turbulent heating (Güsten et al., 85, AA 142. 381).

A circum-nuclear ring of neutral gas and dust (diameter a few pc) originally discovered in the far-infrared (cf. Becklin et al., 82, ApJ 258, 134), has now been studied in the rotational transitions of several molecular lines at 3 mm at resolutions between 20" and 3" with the 30 m IRAM telescope, the 45 m Nobeyama telescope and the Hat-Creek mm-interferometer (Serabyn et al., 86, AA 169, 85; Güsten et al., 87a, ApJ 318, 124; Kaifu et al,, 87, AIP Conf. 155: *The Galactic Center*, ed. Backer). The ring is almost complete, is highly clumped, turbulent and is in strongly perturbed rotation about the center. The excitation, density and temperature of the atomic and molecular gas in the ring is unusually high (cf. Genzel et al., 85, ApJ 297, 766; Harris et al., 85, ApJ Lett. 294, L93). Ionized gas in the radio "mini-spiral" is associated with the ring's sharp inner edge. The velocity field of other ionized gas streamers in the central 2 pc have been studied with the VLA and mid-IR spectroscopy. These data indicate that gas is streaming toward (Serabyn and Lacy 85, ApJ 293, 445) or away from the center (van Gorkom et al., 87, ApJ, in press). The dynamics of neutral and ionized gas in the central 5 pc give substantial, but not fully convincing evidence for a $\approx 10^6$ $M_\odot$ central black hole (for a review see Genzel and Townes 87, Ann. Rev. Astr. Ap. 25). New information on the central mass distribution has also come from the velocity field of OH-IR stars (Winnberg et al., 85, ApJ Lett. 291, L45). The best candidate for a black hole in the center may be the compact radio source Sgr A* (Lo et al., 85, Nature 315, 124). Its proper motion against background quasars indicates that it is located in the galactic center and must be rather massive

(Backer and Sramek 87, AIP Conf. 155: *The Galactic Center*, ed. Backer).

HII Regions and Recombination Lines - High sensitivity radio recombination line (RRL) surveys of galactic HII regions using single dish radio telescopes continue to be important in determining the kinematics and properties of a large sample of galactic HII regions. A northern hemisphere H85, H87 and H88 alpha RRL survey using the 140 foot radio telescope of NRAO with an anglar resolution of 3 arc min at 3 cm has been carried out by Lockman (87, in press). 462 HII regions in the longitude range 350-0-60° were detected. A southern hemisphere survey in the H109 alpha line using the 64 m Parkes telescope with a 4 arc min beam has detected 316 HII regions in the longitude range 210 to 360° (Caswell and Haynes 87 AA 171, 26). Both the Parkes and the NRAO surveys have detected a number of nebulae with low electron temperature; these objects have in addition smaller Doppler line widths (<15 km/s).

Low frequency RRLs have gained in significance in the last years. Anantharamaiah (85 JAA 6, 177 and 203; 86 JAA 7, 131) and Anantharamaiah and Bhattacharya (86 JAA 7, 141) have observed 53 directions in the galactic plane including the galactic centre using the Ooty Radio Telescope. The observations of even lower frequency lines (below 100 MHz) opens up a fascinating new field of RRL research. The carbon line is seen in absorption in the direction of Cas A at these low frequencies (16-30 MHz: Konovalenko 84 Sov Astron Lett 10, 353; 26-68 MHz: Anantharamaiah et al., 85 Nature 315, 647; 42-84 MHz: Ershov et al., 84, Sov Astron Lett 10, 348; 35-240 MHz: Payne et al., 87, in press). The latter observations show that these carbon lines go into emission at frequencies greater than 200 MHz. Additional detections of the carbon lines in the direction of the galactic centre and M16 have been reported by Anantharamaiah et al., (87, in press).

High resolution studies of HII regions using the VLA and the WSRT form the major part of the Ph.D. thesis of P.R. Roelfsema (Groningen, 1987). Hydrogen, carbon and helium RRLs at frequencies from 327 MHz to 14 GHz were observed (H272 to H76 alpha). Spatial variations of the apparent abundance of ionized helium in several compact HII regions have been seen. Apparent helium abundances well in excess of 20 percent have been observed in portions of W3-A. Narrow RRLs of both hydrogen and carbon from the H^0 regions were mapped in the direction of several sources (DR21, K350 and W3).

High frequency mm line observations of RRLs have provided information on the He/H ratio in Orion A and M17 at the 53 alpha line at 43 GHz at Nobeyama (Peimbert et al., 87, Publ Astron Soc Japan, in press). Welch and Marr (87 ApJ 317, L21) have observed the compact HII region W3 (OH) in the H42 alpha line at 86 GHz using the Hat Creek mm interferometer. A systematic change of radial velocity with observing frequency was detected. The H42 alpha velocity is in close agreement with the OH maser and NH_3 absorption velocities. Gordon (87, ApJ, in press) has observed the H40 and He 40 alpha lines from seven HII regions using the 12 m telescope of NRAO at 99 GHz.

VLA observations of the H76 alpha line at 2 cm with an angular resolution of 0.4 arc sec have been made of G34.3+0.2 and G45.07+0.13 (Garay et al., 86 ApJ 309, 553). Large velocity gradients have been observed. Churchwell et al., (87 ApJ 321, 516) have mapped the central 90 arc sec region of the Orion nebula in the continuum at 2 cm using the VLA with an angular resolution of 0.1 to 0.2 arc sec. Twenty nine ultracompact sources (EM > 10^9 pc cm^{-6}) with diameters in the range < 30 to 230 AU were detected.

RRL observations of Sgr A West using both the WSRT and the VLA at 6 and 2 cm are summarized by van Gorkom et al., (84 Proc IAU Sym 106, p 371). Mezger and

Wink (86 AA 157, 252) have mapped Sgr A West using the 100 m telescope of the MPI in the H66 alpha line with an angular resolution of 42 arc sec. H110 alpha (6 cm) emission from the galactic centre ARC has been observed by Yusef-Zadeh et al., (87 The Galactic Center, ed Backer p 190).

Radio observations of extragalactic HII regions are important in determining global, extinction-free parameters. A WSRT survey of M33 at 1.4 GHz (Viallefond et al., 86 AA Suppl. 64, 237) has resulted in the detections of over 100 radio sources associated with H alpha nebulosity. Detailed high resolution VLA observations of the giant HII region NGC 5471 in the galaxy M101 were carried out by Skillman (85 ApJ 290, 449) in the HI line and in the continuum at 20 and 6 cm. Evidence for a supernova remnant imbedded in the HII region was found. Sramek and Weedman (86 ApJ 302, 640) have observed a number of HII regions in M33 and M101 using the VLA at 20 and 6 cm. RRL observations of extragalactic objects are quite difficult due to the low intensities and the large line widths. The gas rich galaxy M82 has been mapped with the VLA at 6 cm in the H110 alpha line (Seaquist et al., 85 ApJ 294, 546) and in the H166 alpha line by Roelfsema (87 Ph.D. thesis, Groningen).

<u>Interstellar Molecules</u> - With the normal operation of the IRAM 30-m telescope (Baars et al. 1987 A&A 175, 316) and the imminent commissioning of the 15-m Maxwell, 10-m Onsala-ESO SEST and the Caltech 10-m High Dish, the future of molecular line observing is very bright. The searches for complex molecular species have been hampered by the large number of mm transitions (see Blake et al. 1987 ApJ 315, 621) but the detection of acetone at 3 mm has been reported by Combes et al. (1987 A&A 180, L13). At shorter wavelengths the lines of HCl (Blake et al. 1985 ApJ 295, 501) and H_2D^+ (Phillips et al. 1985 ApJ 294, L45) are reported. The laboratory measurements of C_3H_2 by Thaddeus et al. (1985 ApJ 299, L63) allowed the identification of many previously unidentified lines, from this very abundant, widespread organic ring molecule. Further progress in identifications was made by measurements of lab spectra for "non-terrestrial" molecules such as C_2S (Saito et al. 1987 ApJ 317, L115) and C_3S (Yamamoto et al. 1987 317, L120). Identifications of C_5H (Cernicharo et al. 1986 A&A 164, L1) and C_6H (Guélin et al. A&A 175, L5) as well as a heavy radical (Gomez-Gonzales et al. 1986 A&A 157, L17) were accomplished without the aid of previously known frequencies. A related development is the possible connection of very small grains with polymers of aromatic ring molecules such as $C_{24}H_{12}$ (Léger and Puget 1984 A&A 137, L5). Compelling evidence for the evaporation of complex molecules from the surface of dust grains has been given by Walmsley et al. (1987 A&A 172, 311) and Plambeck and Wright (1987 ApJ 317, L101). Caution in understanding interstellar chemistry is required, since fundamental problems related to the abundance of CH^+ are still present (Crutcher and Federman 1987 ApJ 316, L71), even after 36 years of study. Complete maps covering large areas in the J=1-0 line of ^{13}CO have been made for the Orion cloud (Bally et al. 1987 ApJ 312, L45) and the Taurus dust cloud (see Kleiner and Dickman (1987 ApJ 312, 839). An analysis for large CO surveys of our galaxy in the J=1-0, ground state line is found in Waller et al. (1987 ApJ 314, 397). The investigation of hot molecular clouds has begun with the detection of the J=7-6 line of CO (Schultz et al. 1985 ApJ 291, L61; Harris et al. 1985 ApJ 294, L93). Fifteen sources were measured in the (7,7) line of NH_3 (Mauersberger et al. 1986 A&A 162, 199).

Observations of CO near the galactic center have been used to study the mass distribution, but no definite proof of the presence of a "Black Hole" has yet been obtained (Crawford et al. 1985 Nature 315, 467; Serabyn et al. 1986 A&A 169, 85).

Using molecular lines, the search for potential protostars such as IRAS 1629A (Walker et al. 1987 ApJ 309, L47; but see Mundy et al. 1986 ApJ 311, L75, and Menten et al. 1987 A&A 177, 231) has been extended to angular scales of 16"-20".

Measurements of many stellar molecular envelopes in CO are in Knapp and Morris (1985 ApJ 292, 640). The use of large single telescopes (see e.g. Likkel et al. A&A 173, L11) and interferometers (see Heiligmann et al. 1986ApJ 308, 306) allows a spatial resolution of structures and provides for the first time the possibility to map out the distribution of different species. Bipolar outflows also give a connection between molecules and stellar evolution. Results are summarized in Lada (1985 Ann Rev. A&A 23, 267). A detailed investigation of the first discovered bipolar outflow source, L1551, shows that on a scale of 20" the molecular disk is not rotating (Batrla and Menten 1985 ApJ 294, L125) or collimating the flow (Walmsley and Menten 1987 A&A 179, 213). In the most energetic outflow, Orion, the line connecting the red and blue shifted lobes is 6"±2" north of the supposed source IRC2 (Wilson et al. 1986 A&A 167, L17).

In external galaxies, the J=2-1 line of CS found in dense galactic regions has been detected by Henkel and Bally (1985 A&A 150, L25). Extragalactic C_3H_2 was found by Seaquist and Bell (1986 ApJ 303, L67), as well as OH absorption from rotationally excited levels (Henkel et al. 1986 A&A 168, L13). Maps of CO have been extended to higher resolution by interferometers (see e.g. Scoville et al. 1986 ApJ 311, L49). Although much of the single-dish flux density is lost, and in extended sources many fields must be mapped, these data could be combined using methods described in A&A 143, 77.

Interstellar Masers - This field has seen tremendous growth in the past three years because of advances in receiver technology and interferometric techniques, the availability of the IRAS data base, and because of the increasing number of telescopes available at cm and mm wavelengths. The major developments in the study of circumstellar masers have been reviewed by Bowers 1985 (Mass Loss from Red Giants p189) and Cohen 1987 (IAU Symp No. 122. 229), and masers in star-forming regions are discussed extensively in the Haystack Symposium Proceedings "Masers, Molecules and Mass Outflows in Starforming Regions" 1986 (particularly reviews by Genzel p233 and Elitzur p299). The impact of QUASAT on study of galactic masers, and the interstellar scattering problem, are discussed by Booth 1984 (ESA-SP 213, 171).

The number of circumstellar maser sources nown now exceeds one thousand. IRAS-based surveys for OH and H_2O masers have been carried out by Engels et al. 1984 (A&A 140, L9), Lewis et al. 1985 (Nature 313, 200), Sivagnanam & Le Squeren 1986 (A&A 168, 374), Zuckerman & Lo 1987 (A&A 173, 263) and others. The detection rate is typically 30%. Surveys of a more traditional type have been carried out by Bowers & Hagen 1984 (ApJ 285, 637, Jewell et al. 1985 (ApJ 298, L55), Slootmaker et al. 1985 (A&A Suppl. 59, 465). Dickinson et al. 1986 (AJ 92, 627), Nyman et al. 1986 (A&A 160, 352), Bujarrabal et al. 1987 (A&A 175, 164) and others. Winnberg et al. 1985 (ApJ 291, L45) have detected a large concentration of 1612 MHz OH-IR sources in the direction of Sgr A.

Extensive monitoring programmes of the major maser lines have been undertaken. Monitoring of OH 1612 MHz OH-IR sources is especially valuable because of its applications to the galactic distance scale. Phase-lag measurements of 1612 MHz maser shell diameters have been made by Herman & Habing 1985 (A & A Supp, 59, 523), and combined with VLA and MERLIN maps to obtain source distances (Herman et al. 1985, A&A 143, 122; Diamond et al. 1985, MNRAS 212, 1). This technique when refined may ultimately give the most accurate measurement of the galactic centre distance. The detection of the first extragalactic OH-IR star in the LMC by Wood et al. 1986 (ApJ 306, L81) encourages even grander hopes.

Results of monitoring circumstellar OH mainline, H_2O and SiO masers have been published by Berulis et al. 1984 (Sov.Inf.Astr.Council. 56, 92), Le Squeren & Sivagnanam 1985 (A&A 152, 85), Gomez Balboa & Lepie 1986 (A&A 159, 166), Clark et

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al. 1985 (ApJ 289, 756), Nyman & Olofsson 1986 (A&A 158, 67), Snyder et al. 1986 (AJ 82, 416) and others. The data give insight on the physical processes occurring nearer to the star. The theory of SiO masers has been comprehensively discussed by Langer & Watson 1984 (ApJ 284, 751), and Cooke & Elitzur 1985 (ApJ 295, 175) have presented a detailed model for circumstellar H_2O masers. Work on pumping the OH mainlines has not yet recovered from the revelation by Andersen 1986 (A&A 154, 42) that the Λ-doublet states of OH have hitherto been incorrectly assigned.

VLA, MERLIN and VLBI maps of circumstellar OH mainline and H_2O masers which probe the main inner regions of circumstellar envelopes have been published by Chapman & Cohen 1985 (MNRAS 212, 375), Diamond et al. 1985 (MNRAS 216, IP), Johnston et al. 1985 (ApJ 290, 660) and Diamond et al. 1987 (A&A 174, 95). The observations of S Per by Diamond et al. resolve H_2O maser spots only ~1 mas in extent. But the most comprehensive data set is that by Chapman & Cohen 1986 (MNRAS 220, 513) for VX Sgr. Observations of OH, H_2o and SiO masers enable the velocity field through this envelope to be studied in detail. Multi-frequency studies of this type hold great promise.

Alcock & Ross have given new impetus to the study of radiative transfer in circumstellar masers in a series of papers on saturation and beaming (ApJ 290, 433; 299, 763; 305, 837, 306, 649 and 310, 838). They point out major defects in the standard shell model, and conclude that the outflow must be clumpy. Observational evidence for this comes from study of SiO masers (Miller et al. 1984, ApJ 287, 892) and the detection of fine structure in the OH profiles of OH-IR sources (Fix 1987, AJ 92, 433 and Cohen et al. 1987, MNRAS 225, 491).

The highlight of the study of interstellar, as opposed to circumstellar masers has been the detection of powerful new methanol masers by Batria et al. 1987 (Nature 326, 49). The 2_0-3_{-1}E maser line at 12 GHz is both widespread and comparable in its photon rate with galactic OH and H_2O masers. It is usually found in association with compact HII regions, but sometimes only absorption is observed. The new maser seems very suitable for interferometric studies. Other methanol masers have been reported by Wilson et al. 1985 (A&A 147, L19), Morimoto et al. 1985 (ApJ 288, L11) and Menten et al. 1986 (A&A 157, 318). VLA observations of W3OH by Menten et al. 1985 (ApJ 293, L83) show that the 9_2-10_1A^+ methanol masers at 23 GHz are excited in the same cloud as the OH masers.

Surveys for interstellar OH and H_2O masers were made by Matthews et al. 1985 (A&A 149, 227), Wouterlout & Walmsley 1986 (A&A 168, 237), Caswell & Haynes 1987 (Aust.J.Phys.40, 215), Braz & Epchtein 1987 (A&A 176, 245), and others. Caswell & Haynes also studies the galactic distribution of OH masers. Two more SiO masers similar to those in Orion-KL where reported by Ukita et al. 1985 (IAU Symp.No. 115, p178).

Interferometric studies of OH and H_2O masers and their relationship to compact HII regions have been carried out by Cohen et al. 1984, (MNRAS 210, 425), Baart & Cohen 1985 (MNRAS 213, 641), Garay et al. 1985 (ApJ 289, 681), Forster & Caswell 1985 (IAU Symp.No. 115, p.174) and others. Garay et al. also measured the H76α and H66α recombination lines from compact HII regions associated with OH masers, to try to establish the dynamics of the maser regions. Maps of excited OH at 6 cm have been published by Palmer et al. 1984 (MNRAS 211, 41P) and Gardner et al. 1987 (MNRAS 225, 469). The highlight of interferometer maping has been the dtermination of the distance to Sgr B2 from VLBI measurements of H_2O proper motions by Reid et al. 1985 (IAU Symp.No. 115, p.554).

Magnetic fields in star-forming regions have been measured from Zeeman spliting of OH maser lines by Benson et al. 1984 (AJ 89, 1391), Baart et al. 1986 (MNRAS 219, 145) and others. The transfer of polarized radiation in cosmic masers in the presence of Zeeman splitting has been treated theoretically by Deguchi & Watson 1986 (ApJ 300, L15 and 302, 750). Rapid variations and flares of masers in starforming regions have been reported by Lehkt & Sorochenko 1984 (Sov.Ast.Let. 10, 307), Haschick & Zisk 1984 (AJ 89, 1387), Mattila et al. 1985 (A&A 145, 192), Rowland & Cohen 1986 (MNRAS 220, 233), Abraham & Vilas Boas 1986 (Rev.MexAstr.Astrof. 12, 228) and others. These studies have been most successful when accompanied by simultaneous interferometer meaaurements to remove the ambiguity of spectral blending. Tarter & Welch 1986 (ApJ 305, 467) have presented a model for H_2Oflares which can account for the rapid timescales observed. However there is still a problem in explaining the luminosities of the most powerful sources. An alternative model by Kylafis & Norman 1986 (ApJ 300, L73) invokes collisions with neutral and charged particles at different temperatures to overcome this difficulty.

EXTRAGALACTIC RESEARCH

Extragalactic source surveys - Large-scale surveys have been reported over a wide range of frequencies. The UTR-2 telescope survey of six frequencies in the 10-25 MHZ band has continued, detecting 313 sources with $52° < \delta < 60°$ (Braude et al. 85 Ap. Space Sci. 111, 1). The 151 MHz 6C survey of 1761 sources stronger than 120 mJy and north of $\delta = 80°$ (Baldwin et al. 85 MN 217, 717) was made with $4\overset{'}{.}2 \times 4\overset{'}{.}2 \operatorname{cosec}\delta$ resolution and is especially sensitive to old, extended radio components. The angular sizes, optical identifications, and size evolution of 6C sources with $S \approx 2$ Jy have been studied (Eales 85 MN 217, 149; 217, 167; 217, 179). The upgraded Bologna telescope produced the B3 408 MHz survey of 13 354 sources complete to 0.1 Jy in a 0.78-sr region $37°15' < \delta < 47°37'$ (Ficarra, Grueff, and Tomassetti 85 AA Suppl. 59, 255). The NRAO 91-m telescope was used to make confusion-limited ($\sigma \approx 30$ mJy) 1400 MHz maps covering $-5° < \delta < +82°$ with $11\overset{'}{.}1 \times 12\overset{'}{.}7$ resolution (Condon and Broderick 85 AJ 90, 2540; 86 AJ 91, 1051).

Wall and Peacock (85 MN 216, 173) combined several high-frequency surveys to generate an "all sky" catalogue of 233 sources stronger than 2 Jy at 2.7 GHz. At 3.9 GHz the RATAN-600 telescope surveyed 0.92 sr in the $0° < \delta < 9°$ band with $4\overset{s}{.}6 \sec\delta \times 52'$ resolution and detected 3 255 sources stronger than 80 mJy (Amirkhanyan et al. 85 Comm. Spec. Ap. Obs. USSR 47). The MIT-Green Bank 5 GHz survey was made with the NRAO 91-m telescope to detect gravitational lens candidates. A total of 5 974 sources stronger than $5\sigma = 53$ to 106 mJy were found in the 1.87-sr region defined by $-00°30' < \delta < +19°30'$<$\delta$<$+19°30'$, $|b|>10°$ (Bennett et al., 86 ApJ Suppl. 61, 1). source counts were obtained by Bennett, Lawrence, and Burke (85 ApJ 299, 373); VLA radio structures and optical identifications of nearly 1000 sources were reported by Lawrence et al., (86 ApJ Suppl. 61, 105).

The narrow strip $32°54'<\delta<33°30'$ was resurveyed with the NRAO 91-m telescope at 5 GHz during 1981 November to detect variations since the original 1970-71 survey (Altschuler 86 AA Suppl. 65, 267). The spectral-index distributions and counts of sources selected at 4850 MHz were investigated by three surveys made with the MPIfR 100-m telescope. A 9.2×10^{-3}-sr portion of the 1400 MHz GB survey region (Maslowski et al., 84, AA 141, 376) and 6.6×10^{-3} sr of the 408 MHz 5C2 survey area were resurveyed. (Maslowski et al, 84, AA 139, 85). Benn et al., (84 MN 209, 683) mapped 4.7×10^{-3} sr of the 5C 12 field. These surveys confirm the convergence of the 5 GHz source counts and the declining fraction of flat-spectrum sources at low flux densities. Aperture-synthesis surveys have covered a number of small areas with higher sensitivity and resolution. The 5C 20 survey centred on Abell 2218 found discrete sources at 408 and 1407 MHz that might affect measurements of the Sunyaev-Zeldovich effect (Birkinshaw 86 MN 222, 731). Four Einstein deep X-ray survey fields were mapped at 608.5 and 1412 MHz with the WSRT, (Katgert-Merkelijn et al., 85 AA Suppl. 61, 517). Sensitive ($\sigma \approx 0.2$ mJy) MOST maps of $25 \approx 1°$-diameter fields made with 43" x 43" $\operatorname{cosec}\delta$ resolution have been used to

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determine the 843 MHz source count to S=1mJy (Subrahmanya and Mills 87 Proc. IAU Symp. 124, 569).

The Leiden-Berkeley Deep Survey (LBDS) is a major radio/optical project to study faint radio galaxies. The WSRT 3-km array mapped four high-latitude fields covered by deep multicolor KPNO 4-m telescope plates, detecting 306 sources stronger than $5\sigma(\geq 0.6$ mJy) at 1412 MHz [with 12".5 x 12".5 cosecδ resolution] (Windhorst, van Heerde, and Katgert 84 AA Suppl. 58, 1). Optical identifications (Windhorst, Kron and Koo 84 AA Suppl. 58, 39), broadband photometry, and spectroscopy (Kron, Koo and Windhorst 85 AA 146, 38) reveal an increasing population of blue galaxies associated with sources fainter than 10 mJy. The Lynx.2 field ($\alpha=8^h41^m46^s$, $\delta=+44°46'50"$) was mapped at higher sensitivity with both the WSRT 3-km array (Oort and Windhorst 85 AA 145, 405) and the VLA C-array (Windhorst et al., 85 ApJ 289, 494). High resolution VLA A-array snapshot maps of 133 LBDS sources show that their angular sizes decrease with flux density in the 1-10 mJy range (Oort et al., 87 AA 179, 41).

The deepest 1.49 GHz VLA map of a single primary-beam area (30' FWHM) at $\alpha=13^h00^m37^s$, $\delta=+30°34'$ reached the confusion limit ($\sigma_n=10$ μJy, $\sigma_c=11\mu$Jy) for 17".5 resolution, yielding direct source counts to 84 μJy and statistical P(D) counts down to 10 μJy (Mitchell and Condon 85 AJ 90, 1957). Significantly deeper surveys can be made only with higher resolution. The angular-size distribution of sub-mJy sources was estimated from a 5".8-resolution VLA B-array map with $\sigma=21$ μJy [at $\alpha=8^h52^m15^s$, $\delta=+17°16'$]; the median angular size of sources fainter than 400 μJy atr 1.465 GHz is $\langle\theta\rangle\leq 3"$ (Coleman and Condon 85 AJ90, 1431), significantly lower than the value $\langle\theta\rangle\approx 10"$ found for S $\geq$ 10 mJy.

The source counts and angular-size distributions obtained by different groups observing independent areas of sky with both the WSRT and the VLA agree within the $\sqrt{N}$ statistical uncertainties in samples of N sources, suggesting that clustering in the small areas covered ($\approx 10^{-4}$ sr) does not distort the results. The unexpectedly large number of compact sub-mJy sources is well established at 1.4 GHz, but their nature and space distribution remain to be determined (cf. Wall et al., 86 Highlights Astron. 7, 345; Windhorst 86 Highlights Astron. 7, 355).

Some 6 cm VLA D-array surveys approach the discrete-source confusion limit and may also be affected by small-scale (<1') fluctuations in the 3K cosmic background radiation. One deep field ($\geq$=11 μJy) and ten intermediate-sensitivity fields (σ=68 μJy) were mapped at 18" resolution, yielding source counts to 60 μJy (Fomalont et al,m 84 Science 225, 23). Partridge, Hilldrup, and Ratner (86 ApJ 308, 46) reached 100 μJy with VLA C- and D-array maps. Source counts in the 25-400 μJy range (Kellermann et al., Highlights Astron. 7, 367) were obtained from the deepest 6 cm VLA D-array survey ($\sigma_n\approx 4.5$ μJy). the sub-mJy 6 cm counts agree within their $\sqrt{N}$ errors, which are large because N is still small. More deep 6 cm surveys are needed, with overlapping 20 cm maps to define the spectral-index distribution of the faintest sources.

Cosmological tests - Counts of radio sources at the mJy and sub-mJy level have been reported from surveys near 1.4 GHz using the VLA (Coleman et al 85 AJ 90, 1437; Mitchell et al 85 AJ 90, 1957) and the Westerbork array (Katgert-Merkelijn et al 85 AA Supl 61, 547; Oort and Windhorst 85 AA 145, 405; Windhorst et al 85 ApJ 289, 494) and near 5 GHz using the VLA (Kellermann et al 86 Highlights of Astronomy, Vol 7, p 367; Partridge et al 86 ApJ 308, 46). Subrahmanya and Mills (87 IAU Symp 124, p 569) have estimated the counts at 843 MHz for the entire range of flux density down to aproximately 1 mJy based on observations with a single instrument, the Molonglo Synthesis Telescope.

The deepest counts now reach source densities of approximately 10^6/steradian. There is reasonably good agreement on the observed upturn in the normalized differential counts below approximately 1 mJy, at both 1.4 and 5 GHz in different fields over the sky, suggesting the emergence of a new population of sources at these flux leves. the nature of this population is however not well understood and remains controversial (Windhorst 86 Highlights of Astronomy Vol 7, p355; Wall et al. 86 Highlights of Astronomy Vol 7, p 345). It is becoming clear from deep optical identifications and spectroscopy (Windhorst et al. 84 AA Supl. 58, 39; Kron et al. 84 AA 146, 38; Windhorst et al. 87 IAU Symp. 124, p 573; Downes et al. 86 MNRAS 218, 31; Mitchell and Condon 85 AJ 90, 1957; Weistrop et al. 87 AJ 93, 805), however, that at low flux levels one is seeing more and more of the moderately active galaxies of relatively lower radio and optical luminosity.

V/V_m tests on large samples of bright sources at 2.7 and 5 GHz have confirmed that strong evolution is required for high luminosity sources of both steep as well as flat spectrum (Wall and Peacock 85 MNRAS 216, 173; Marrides and Mutus 84 AA 131, 81). Free-form models of the epoch dependence of the radio luminosity function also support this conclusion (Peacock 85 MNRAS 217, 601; Zawislak-Raczka and Kumor-Obryk 86 MNRAS 222, 487). This is true also in the evolutionary model reported by Condon (84 ApJ 287 461) which uses a combination of density and luminosity evolution but treats all sources in the same way.

The need for evolution with epoch in the linear sizes of extended radio sources based on angular size - redshift (θ-Z) tests has in the past been difficult to establish because of the inability to distinguish such evolution from the effects of a possible inverse correlation between radio luminosuity and linear size. From studies of the θ-Z relations for radio galazies of similar luminosity, it now appears that strong evolution in linear size is indeed necessary (Kapahi 85 MNRAS 214, 19; Eales 85 MNRAS 217, 179; Gopal-Krishna et al. 86 IAU Symp 119, p 193; Oort et al. 87 AA 179, 41). It is also becoming clear that there is a weak but <u>direct</u> correlation between luminosity and size for radio galaxies (Machalski and Condon 85 AJ 90, 973; Kapahi 86 Highlights of Astronomy Vol. 7, p 371; Oort et al. 87 AA 179, 41).

In the case of quasars, although the observed θ-Z relation is similar to that for galaxies (Kapahi 87 IAU Symp 124, p251), interpretation is less simple because of the difficulty of defining reasonably complete and unbiased samples.

The effect of various selection effects on the interpretation of the angular size - flux density (θ-S) relation has been discussed by Allington-Smith (84 MNRAS 210, 611). Comparison of the observed θ-S relation at 408 MHz with predictions based on several strong-source samples and evolution models of the RLF shows that the data cannot be fitted without invoking size evolution (Kapahi et al. 87 JAA 8, 33).

Gopal-Krishna and Wiita (87 MNRAS <u>226</u>, 531) have investigated the interaction of jets with hot galactic haloes and an intergalactic medium in order to explain the observed evolution in linear sizes.

High resolution VLA observations of mJy and sub-mJy sources from surveys at 1.4 GHz show that the median angular size at these flux levels drops to $\lesssim$3" arc (Coleman and Condon 85 AJ 90, 1431; Oort and Windhorst 85 AA 145, 405; Oort et al. 87 AA 179, 41) compared to the value of approximately 10" arc at higher flux levels. This appears to be related to the emergence of the new population of galaxies at the faintest levels which have a smaller radio size than the ellipticals.

Flux densities and spectra - Measurements of flux densities and spectra of active radio sources have been reported over a wide range of frequencies. Braude et al (85 Ap Sp Sci 111, 237) have extended the spectra of 114 sources down to 12 MHz. Roger et al. (86 AA Sup 65, 485) have reported flux densities of 395 sources at 22 MHz. Tovmassian et al (84 AA Sup 58, 317) have observed 464 Markarian galaxies at 2.7 GHz leading to 14 detections. Flux densities of sources in the 5C2 survey region have been measured at 5 GHz and used to investigate the dependence of spectral index on flux density for samples defined at 1.4 and 5 GHz (Maslowski et al 85 AA 139, 85). Kulkarni and Mantovani (85 AA Sup 61, 1) have reported measurements of flux density at 5 GHz for 184 sources selected from the B2.3 survey, which have been used to improve the spectral index-flux density correlation for source samples defined at 408 MHz (Kapahi and Kulkarni 86 AA 165, 39). Lawrence et al (86 ApJ Sup 61, 105) have published spectral indices for a large sample of 632 sources from the MIT-Green Bank Survey at 5 GHz.

At shorter wavelengths, Tabara (84 PAS Jap 36, 297) has measured at 10 GHz flux densities of 135 weak flat-spectrum sources. A sample of 95 sources has been observed at 22 and 37 GHz by Efanov et al (84 Izv Krymskoy Astrofiz 69, 78). Valtaoja et al (85 Izv. Krymskoy Astrofiz. obs. 70, 144) have reported coordinated observations of 20 sources in the 11-37 GHz range. A second list of 25 'gigahertz-peaked-spectrum' sources has been prepared, to facilitate searches for compact doubles and high-redshft sources (Spoelstra et al 85 AA 152, 38).

Weak radio nuclei of powerful radio sources are shown to have distinctly more curved radio spectra than strong "flat-spectrum" sources selected at 5 GHz and, thus, they may not be merely scaled-down versions of the latter (Rudnick et al 86 AJ 91, 1011). Synchrotron spectra of the hotspots of powerful radio sources have been shown to extend to near-infrared wavelenths in cases of 3C33 and 3C273 and perhaps to X-ray band in Pictor A (Röser and Meisenheimer 87 ApJ 314, 70).

Relationship of the compact and extended radio emission of quasars to their optical and X-ray emission and the possible role of relativistic beaming at all these bands has been quantitatively examined (Browne and Murphy 86 MN 226, 601, see also Kembhavi et al 86 MN 220, 51 and Feigelson et al 84 AJ 89, 1464). Robson et al. (85 MN 213, 355) have reported non-detection of a dozen radio-quiet quasars at 1 mm wavelength down to a flux density generally below 1 Jy.

Much effort has been devoted to combine the radio flux measurements of the active galactic nuclei with their observations (often, quasi-simultaneous) at higher frequencies reaching up to the X-ray band in several cases. Considerable improvement has thus been attained in understanding the physical mechanisms and the inter-relationship of the nuclear emission in the different wave bands, in disentangling the thermal and non thermal components and in assessing the role of opacity effects and of the postulated bulk relativistic motion of the radiating plasma. Such studies comprise those involving special individual objects such as NGC1275 (Longmore et al. 84 MN 209, 373; Gear et al 85 MN 217, 281), 3C345 (Bregman et al 86 ApJ 301, 708), 3C446 (Brown et al 86 MN 219, 671), Mrk421 (Makino et al 87 ApJ 313, 662) and 3C273 (Courvoisier et al 87 AA 176, 197), as well as samples of blazars/flat-spectrum radio sources (e.g., Mufson et al 84 ApJ 285, 571; Worrall et al 84 ApJ 286, 711; Gear et al. 85 ApJ; 291, 511; Ledden and O'Dell 85 ApJ 298, 630; Lépine et al (85 AA, 149, 351); Roellig et al 86 ApJ 304, 646). Based on similar multi-band observations, substantial differences of spectral and other properties have been reported between the radio-selectred and X-ray selected blazars (Stocke et al. 85 ApJ 298, 619; Ghisellini et al. 86 ApJ 310, 317, Marasch et al. 86 ApJ 310, 325). Landau et al. (86 ApJ 308, 78) have used their near-simultaneous, multifrequency observations of 15 blazars over the radio-optical range to conclude that the global spectra of all these sources can be well fitted with smoothly varying functions like parabolae and that interesting correlation is present between the fit parameters. This hints towards a common

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regulating mechanism for active extraglactic sources.

Structure of Radio Galaxies and Quasars - Multifrequency mapping and high-sensitivity, high-dynamic range observations with a variety of synthesis telescopes - the VLA, MERLIN, Cambridge, Westerbork, Fleurs, Molonglo and Ooty - have produced a wealth of new information on extragalactic radio sources on scales from about 0.1 arcsec to many minutes of arc. Excellent reviews have appeared in several conference proceedings e.g. the NRAO Workshop No. 9 on "Physics of Energy Transport in Extragalactic Radio sources" (ed. A H Bridle & J A Eilek) (hereafter PETER), IAU Symposium No. 119 on "Quasars" (ed. G Swarup & V K Kapahi), the Canadian Institute for Theoretical Astrophysics conference on "Jets from Stars and Galaxies" (ed. R N Henriksen) (Canadian J Phys 64, 351), the 1986 Erice Summer School on "Astrophysical Jets and their Engines" (ed W Kundt).

Surveys of source structure - Statistical analysis of the structural properties of complete samples of radio sources leads to useful constraints on physical models of these objects. Fanti et al (87 AA Supp 69, 57 and references therein) have now completed VLA observations of the B2 sample of about a hundred low luminosity radio galaxies and Machalski & Condon (85 AJ 90, 5; 85 AJ 90, 973; 86 AJ 91,998) have made VLA observations of a complete sample of intermediate-strength radio sources selected from the GB/GB2 1400-MHz surveys. Thirty extragalactic 3C sources in the Galactic plane have been mapped with the Cambridge 5-km telescope (Pooley et al 87 MNRAS 224, 847). Pearson et al (85 AJ 90, 738) have mapped 36 compact sources from the 3C catalogue with the VLA with resolutions of 0.4 arcsec. These are mostly steep-spectrum objects, many of which look like small angular-size doubles, though there is a variety of structures; however none of the steep-spectrum objects are like the few flat-spectrum 3C sources which have dominant cores and one-sided arcsecond jets. There have been a number of VLA surveys of the structures of quasars. Gower & Hutchings (84 AJ 89, 1658) have mapped low redshift quasars, Rogora et al (86 AA Supp 64, 557; 87 AA Supp 67, 267) have looked at 74 B2 quasars and Owen & Puschell (84 AJ 89, 932) have mapped 26 quasars from the Jodrell Bank 966-MHz survey.

Jets - Bridle (84 AJ 89, 979; 86 Canadian J Phys 64, 353) and Bridle & Perley (84 ARAA 22, 319) summarize and discuss the overall properties of extragalactic jets. The jets in lower luminosity sources (less than 10^{25} WHz^{-1} at 1.4 GHz) are two-sided and smooth and dominated by perpendicular magnetic fields whilst those in the more powerful double sources are one-sided and knotty with parallel magnetic fields. The jets in the lower luminosity sources also spread more rapidly.

Multifrequency mapping has revealed much about the physics of these jets. Perhaps the most exciting observations are those of the double-lobed source 3C 120 (Walker et al 87 ApJ 316, 546). A sequence of maps with increasing resolution shows that the jet is continuously connected from within 1 pc of the central engine to over 100 kpc away, well outside the associated galaxy, and gradually bends through about 90°. The source exhibits superluminal motions on parsec scales with features which move outwards, and the fact that this is continuous with the large scale jet is the best evidence available to date that material is moving outwards in these kpc-scale jets; the velocities on parsec scales are presumably relativistic but there is little constraint on the velocity of the large scale jet. Synchrotron radiation from jets probably results from particle acceleration in shocks produced by the interaction between the jets and the surrounding medium. VLA maps of the inner 700 pc of the Cen A jet (Clarke et al 86 ApJ 300, L41) which show it to consist of limb-brightened knots which alternate from side to side strongly support this suggestion. Observations also indicate that jets are light and not usually free; limits on the surrounding hot gas indicate that they can in general be confined by thermal pressure (e.g. 3C 219,

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Bridle et al 86 AJ 92, 534) though this is almost certainly not the case for the jet in Cygnus A (Dreher et al 84 PETER, 57) for which magnetically-assisted collimation is proposed.

Multifrequency maps of the jets in the narrow-angle tail source NGC 1265 in the Perseus cluster (O'Dea and Owen 86 ApJ 301, 841; 87 ApJ 316, 95) are consistent with a model in which the jets have been bent by the motion of the galaxy through the cluster gas. The magnetic field near the core is parallel to the jet as expected if a tangled magnetic field is sheared tangentially to the jet surface. In the outer parts of the jets, where they spread rapidly, the magnetic field is perpendicular to the jet axis - this can be attributed to expansion and deceleration. Similar behaviour is observed in the jets of 3C66B (Leahy et al 86 AA 156, 234). The jets in high-power sources also exhibit bends and wiggles. The bends, which are often quite sharp e.g. 1759 + 211 (Saikia et al 87 MNRAS 224, 53), 4C 29.50 (Lonsdale & Barthel 86 ApJ 303, 617), are attributed to collisions with dense clouds of inter- or intra-galactic gas. The wiggles and oscillations, such as those observed in 3C 273 (see below), 1759+211 and 0800+608 (Shone & Browne 86 MNRAS 222, 365) are generally thought to be due to hydrodynamical instabilities.

As already noted, the jets in powerful sources are one-sided; of the one hundred known quasar jets none is clearly two-sided (Owen 86 Quasars, 173). There is a correlation between jet and core power (Burns et al 84 ApJ 283, 515) and the strengths of both core and jet are the outstanding differences between radio galaxies and quasars. Given that some of these cores are also superluminal, there is, at first sight, strong evidence that the one-sidedness of the kpc-scale jets in powerful sources is due to relativistic beaming. Contrary evidence is provided by the fact that the projected linear size distributions for sources with and without jets are not significantly different and by the asymmetries in the outer lobes (e.g. Saikia 84 MNRAS 209, 525). Further, observations of the quasar 3C 273 with MERLIN at 151, 408 and 1666 MHz (Foley & Davis 85 MNRAS 216, 679; Flatters & Conway 85 Nature 314, 425; Davis et al 85 Nature 318, 343) indicate that it is intrinsically one-sided. The jet is continuous from the core to beyond the optical jet, and there is an extended lobe associated with this jet; there is however no counter lobe. Whilst the jet motion is likely to be relativistic throughout, Doppler beaming factors must be too small to hide the counter lobe. The jet one-sidedness in the inner regions of some low-luminosity sources is also intrinsic (Laing 84 PETER 119). There <u>are</u> faint counter jets in the powerful radio galaxies 3C 219 (Bridle et al 86) and Cygnus A (Dreher et al 84) which could be accounted for if the jets are symmetric but contain relativistically moving shocks. It is interesting however that the counter jet components are at the same distance from the core as a gaps in the jet so that the jet - counter jet asymmetry could be a result of episodic energy transport or flip-flop (Rudnick 84 PETER, 35).

Core-dominated sources and unified schemes - In the unified schemes the differences between core- and lobe-dominated sources is simply a function of the angle that they make with the line-of-sight - the core-dominated sources being Doppler boosted. High resolution, high dynamic range observations of core-dominated sources have revealed extended structure on arcsecond scales in the majority of them (e.g.Browne & Perley 86 MNRAS 222, 149; Antonucci & Ulvestad 85 ApJ 294, 158; Antonucci et al 86 AJ 92, 1; Antonucci 86 ApJ 304, 634; Saikia et al 86 Quasars, 219) and are in broad agreement with the predictions of the unified schemes as far as the observed strength and size of the radio emission is concerned. However the facts that the extended emission around core-dominated sources is sometimes very large (> 100 kpc) (de Bruyn & Schilizzi 86 Quasars, 203) and that some double sources with projected sizes of several hundred kiloparsecs have superluminal cores (Shone et al 85 Nature 314, 603; Zensus et al 87 Nature 325, 36) are difficult to accommodate in the schemes. They can remain tenable only if there is gross misalignment between the inner and outer structure in a few sources, such as observed in 3C 120 (Walker et al 87), Mark 501 (van Breugel & Schilizzi 86 ApJ 301, 834) and 1928+738 (Johnston et al 87 ApJ 313, L85). Other tests of the schemes come from comparison of optical, X-ray and radio properties of quasars. Kembhavi et al (86 MNRAS 220, 51) and Browne & Murphy (87 MNRAS 226, 601) have looked at the correlations between radio luminosity and X-ray luminosity and conclude that their results are consistent with a two-component origin for the optical and X-ray emission, one of which is isotropic and one relativistically beamed.

Lobes and Hotspots - Multifrequency observations of radio sources have provided a wealth of data on spectral ageing, magnetic field configurations, flow directions and matter densities in the lobes, interactions of sources with their environments and on matter distributions in the intervening regions.

The radio spectra in different regions of double radio sources are, in general, well fitted by synchrotron-loss curves (e.g. Alexander 87 MNRAS 225, 27) from which relative ages for the regions can be deduced. The results are consistent with models in which particle acceleration occurs in the hotspots which advance into the intergalactic medium leaving the radiating material behind (e.g. Myers & Spangler 85 ApJ 291, 52; Alexander & Leahy 87 MNRAS 225, 1). If the hotspots are fed by light jets, backflow of the lobe material also occurs. Supporting evidence for the existence of backflow comes from detailed mapping of the lobes and bridges (Leahy & Williams 1984 MNRAS 210, 929) which show that they are markedly distorted near the central galaxy. The rate of separation of hotspot and lobe material is typically ~ 10^3 - 10^4 km s^{-1}; it correlates with luminosity and may be as high as ~ 0.2 c in the most powerful sources. The bridges get narrower relative to their length at higher powers, consistent with the greater expansion speeds (Leahy et al 86 Quasars, 189).

The magnetic fields in these double sources follow the contours of total intensity and are either parallel or perpendicular to ridge lines (Leahy et al 86 MNRAS 222, 753; Miller 85 MNRAS 215, 773; Spangler et al 84 AJ 89, 1478) and the fractional polarization is high. The magnetic field geometry is that expected for fluid distortions associated with backflow. The depolarization and rotation measure observations do not provide definite evidence on the existence of cold matter within the sources. There is however strong evidence for differential rotation produced by the medium surrounding a source and in our Galaxy. Strom & Conway (85 AA Supp 61,547) find from polarization maps made at 49 cm that there is little or no polarized emission within a 50 kpc radius of the associated object, suggesting that the thermal gas surrounding the object is providing the Faraday depolarization. Leahy et al (86) confirm that the rotation measure and depolarization correlate with luminosity and find that rotation measure variations are usually larger on the brighter side of a source; it seems likely that this is because the brighter component is interacting with denser material. Leahy (87 MNRAS 226, 433) has investigated the effect of our Galaxy on rotation measure and concludes that the observed variations on scales of 5 - 200 arcsec may be due to small faint HII regions along the line of sight.

Detailed observations of Cygnus A have produced a number of remarkable results. Dreher et al (85 PETER, 57) present a multiconfiguration VLA map showing the jet, counter jet, complex fine structure in the lobes with wispy structure near the heads, thin arcs and apparent sideways shocks, and very hard edges to the lobes suggesting ram-confinement. Spectral variations in the lobes at high frequencies (Alexander et al 84 MNRAS 209, 851) and between 81.5 and 2700 MHz (Spinks et al 86 Nature 319, 471) imply that the speed of the lobe material relative to the hotspots in ~ 0.1 c. Dreher et al (87 ApJ 316, 611) have made a detailed study of Faraday rotation in Cygnus A. The rotation, which must be in a Faraday screen near the radio source, in the cluster gas or possibly in a denser sheath round the lobes, varies over an enormous range between -4000 and +3000 rad m^{-2} and requires field reversals over scales of 20-40 kpc. The external magnetic field required is very high and its origin is a mystery.

A number of classical double sources including Cygnus A have double hotspots, one of which is markedly more compact than the other and lies closer to the source axis (Lonsdale & Barthel 86 AJ 92, 12). Williams & Gull (85 Nature 313, 34) have found that jet deflection in a single-jet fluid-dynamical model produces such structures; the compact subcomponent occurs where the jet meets the cocoon wall and the more diffuse subcomponents then result as "splatter spots".

Tailed and other low luminosity sources - Observations of Abell clusters (e.g. O'Dea & Owen 85 AJ 90, 927) have resulted in the discovery of many narrow-angle tailed (NAT) and wide-angle tailed (WAT) radio galaxies. There are now sufficiently large numbers of these objects to investigate their global properties. O'Dea & Owen (85, AJ 90, 954) find that the dominant influence on the radio structure of NATs is the motion of the associated galaxy through the cluster and O'Dea et al (87 ApJ 316, 113) conclude that neither gravity nor buoyancy predominates in determining the curvature of the tails. Burns (86 Can J Phys 64, 373) reviews the properties of WATs which he divides into three subclasses by linear size. He suggests that the smallest (e.g. that in the Coma cluster galaxy NGC 4874, Feretti & Giovanni 85 AA 147, L13), which are limited to the optical extent of the associated galaxies, are bent by dynamic pressure as a result of the motion of the radio galaxy through the cluster. The largest WATs are about 1 Mpc in size and often associated with cD galaxies; the jets exhibit abrupt bends (e.g. 1919+479, Burns et al 86 ApJ 307, 73) which probably result from an interaction between the jet and clouds in the cluster gas. Stocke et al (85 ApJ 299, 799) and Saikia et al (87 MNRAS 224, 911) propose a similar mechanism to explain the abrupt bends in the radio structure of some quasars. Moderate sized WATs, such as that associated with NGC 2329 (Feretti et al 85 AA 147, 321), may bend and decollimate as a result of the passage of the jets through sharp pressure gradients in galaxy halos. One of the most exciting discoveries is the WAT source, 3C 75, in Abell 400 (Owen et al 85 ApJ 294, L85) which has a pair of twin jets originating in the double nucleus of the associated galaxy; the jets bend in the same directions and on larger scales appear to merge.

Detailed optical and radio observations by van Breugel et al (85 ApJ 290, 496) of 3C 277.3 show that the brightest emission-line gas is found next to the brightest radio features and a shell-like Hα structure bounds most of the northern radio lobe. The presence of emission-line gas and depolarization are correlated. They suggest that the jets are propagating through a cloudy medium and that this material is excited and accelerated by these jets. A similar correlation between unpolarized emission and emission-line gas is observed in 4C 29.30 (van Breugel et al 86 ApJ 311, 58).

Leahy et al (86) have made a multifrequency study of the twin-jet source 3C 66B. It is the first source for which the correlation between depolarization and rotation measure implies that some of the rotation must be occurring within the lobes; the inferred density is $>10^3$ m^{-3}, very similar to that in the external medium detected in X-rays, indicating that matter may have entered the lobe by entrainment.

<u>VLBI</u> - The Proceedings of IAU Symp 119 "Quasars" (86 eds. Swarup and Kapahi) of IAU Symp 129, "The Impact of VLBI on Astrophysics and Geophysics" (1988, eds. Moran and Reid) and the volume on "Sumperluminal Radio Sources" (1987, eds. Zensus and Pearson, Cambridge University Press) contain many recent accounts of research relevant to this section.

Over the last four years much of the work in this section has focussed on the role of relativistic beaming in theories of powerful extragalactic radio sources and the superluminal phenomenon (see, eg. Begelman et al. 84 Rev Mod Phys 56, 255). There have been two major lines of attack on these problems, viz. VLBI surveys of large samples of powerful objects and detailed studies of a few objects at many epochs and frequencies.

VLBI surveys: A number of major VLBI surveys have been actively pursued over the last four years. These fall into two categories - surveys of compact objects, of which a high fraction are detectable with the Mark II VLBI system, and surveys of the central components of extended triple sources which require the sensitivity of the Mark III system.

The major programs in the first class are those of Pearson and Readhead (88 Ap. J. in press), Witzel and his collaborators (87 in Superluminal Radio Sources, p. 83), and the high frequency survey of Lawrence et al (85 Ap.J. 296, 458). These programs have the broad objectives of discovering the full range of source morphologies, providing statistically complete samples for testing theoretical models and searching for new superluminal sources.

A carefully selected group of triple radio sources suitable for statistical tests of theoretical models has been defined by Cawthorne et al. (86 MNRAS 219, 883). There are three major ongoing programs on the central components of triple sources, by Barthel et al (84 AA 140, 399), Hough and Readhead (87 "Superluminal Radio Sources", P. 114) and Zensus and Porcas (IAU Symp 119 p. 167).

Through these surveys a number of new superluminal sources have been found (Barthel et al. 86 Ap.J. (Letters), 296 L23; Eckart et al 85 Ap.J. Letters), 296 L23; Eckart et al 86 AA 168, 17; Hough and Readhead 87 Ap.J.(Letters) in press; Pearson et al. 86 Ap.J)Letters), 300, L25; Zensus et al. 87 Nature 325, 36). It is now clear that all classes of powerful extragalactic radio sources, except the compact doubles with steep high frequency spectra, display superluminal motion.

Thus far only three superluminal sources have been found in the surveys of the central components of triple sources, but the mean apparent velocity of this class of object is significantly lower than that of the compact flat spectrum sources. This result is consistent with simple beaming models for these objects, but there are a number of results which show that the simplest models are no longer tenable. In particular, they predict that for each compact flat spectrum source, identified on this model with a nuclear jet whose axis is close to the line of sight, there are about fifty objects whose jet axes are not close to the line of sight. There appear to be too few quasars with the correct properties to constitute this parent population. Phinney (85 in "Astrophysics of Active Galaxies and Quasi-Stellar Objects" ed. Miller, University Science Books) and Readhead et al. (88 IAU Symp 129) have summarised these arguments. In addition the overall sizes of superluminal sources when deprojected according to the simplest beaming models are uncomfortably large (Barthel 87 in "Superluminal Radio Sources".

There is one other important VLBI survey which has been made of the steep spectrum compact objects (Fanti et al. 85 AA 143, 292; Fanti and Fanti 87 "Superluminal Radio Sources" p. 174; Fanti et al. 88 IAU Symp 129). This has shown these objects comprise a class of randomly oriented, intrinsically small sources, and are not simply extended triple objects viewed end-on.

Detailed Observations of Individual Objects: The most extensively studied compact radio source is 3C345 (Biretta et al. 86 Ap.J 308, 93: Biretta and Cohen 87 "Super luminal Radio Sources" p. 40). In this object a new radio component was observed to increase in apparent speed from a subluminal speed to an apparent speed of 10c between 1978 and 1985. In addition the new component itself expanded superluminally. There is now some evidence that successive components in this object are following the same path as earlier components, but this has not yet been definitively demonstrated. If this result is confirmed it will provide very important constraints on theories of superluminal sources.

Another object which has been intensively studied is 3C120 (Walker et al. 87 "Superluminal Radio Sources" p. 48). In this object a continuous jet can be traced from the most compact structures observed in VLBI observations, on parsec scales, out to the outer lobes.

It has now been establised that BL Lac is a superluminal source (Mutel and Phillips 87 "Superluminal Radio Sources"), and that some compact steep spectrum sources are superluminal (Wilkinson et al 86 IAU Symp 119 p. 165).

In 4C39.25 and 3C395 superluminal motion has been detected in a component which is straddled by two apparently stationary components (Shaffer and Marscher 87 "Superluminal Raido Sources" p. 67; Simon et al. 88 IAU Symp 129). It is clearly of great importance to monitor these objects and to determine whether the most widely separated components are indeed stationary, since this could strongly constrain the theories of superluminal motion.

In 3C 84 (Maars et al. 88 IAU Symp 129) the existence of a compact component at a projected distance of 2 pc from the flat spectrum core has been confirmed, and it has been found that this component is moving at an apparent speed of 0.4c relative to the core. In addition, a jet-like feature close to the core has shown significant position angle changes over a five year period, and it is clearly important to monitor this motion to determine whether it repeats periodicaley, as might be expected for example, if it were caused by precession.

<u>Extragalactic Molecules</u> - The release of the IRAS data spurred much work, including searches for CO in highly luminous infrared galaxies, such as Arp220 and NGC6240 (Sanders and Mirabel 85 ApJ 298 L31; Young et al., 84 Ap.J. 287 L65). The most distant galaxy detected in CO is VIIZw31 at z=0.054 (Sage and Solomon 87 preprint). The report of the second IRAS Conference (C.J. Persson 8 Conf Pub 2466 NASA: Washington) includes papers by most groups active in extragalactic molecular research and is a good summary of the state of the field in mid 1986.

High Infrared Luminosity Galaxies. Studies of these galaxies, whose luminosities can equal those of quasars, have shown that the CO luminosity, which traces molecular gas, is well correlated with the far infrared luminosity, though the most luminous galaxies have higher values of L_{FIR}/L_{CO}, probably due to higher dust temperatues caused by increased star formation (Young et al., 86 ApJ 304 443). Sanders et al., 86 (ApJ 305 L45) present evidence that the cause may be galaxy collisions. The relation betwen active galaxies and starbursts is still unclear. Although L_{FIR}/L_{CO} for highly luminous galaxies is similar to that in starburst galaxies such as M82, interferometry (Scoville et al., 86 ApJ 311 L47) shows more extreme conditions in Arp 220, with a CO emitting region coincident with the compact nucleus and less than 1.5 kpc in extent containing 10^{10} solar masses of molecular material.

Normal Galaxies. There have been many investigations of normal galaxies, with the aims of correlating CO emission with other properties, and searching for spiral structure. Samples of Virgo spirals (Young et al., 85 ApJ 288 487; Stark et al., 86 ApJ 310 660) show a good correlation between L_{FIR} and L_{CO}, and little variation of L_{CO} with spiral type, although CO is more centrally peaked in late type spirals. Unlike HI, CO content does not vary with position in the cluster.
High resolution observations with interferometers and large single dishes are

beginning to detect molecular structure in many nearby galaxies. For example, the CO gas in the nucleus of IC342 was shown to lie almost entirely in a bar with a length of 1.5 kpc (Lo et al., 84 ApJ 282 L59) and molecular spirals arms were detected in the inner part of M51 (Lo et al., 87 ApJ 317 L63; Rydbeck et al., 85 AA 144 282) though most of the gas forms a smooth distribution between the arms. A similar result is found in M31, in which CO spectra show a narrow, spatially resolved feature, due to giant molecular clouds, superposed on a ubiquitous, weak, broad line which is presumably due to an ensemble of smaller clouds (Boulanger et al., 84 AA 140 L5; Blitz et al., 85 ApJ 296 481; Ryden and Stark 86 ApJ 305 823; Ichikawa et al., 85 PASJ 37 439). An individual GMC in M31 has been imaged by Vogel et al., 87 (preprint).

VLA maps of OH absorption in M82 (Weliachew et al., 84 AA 137 335) showed that the dense molecular gas in M82 was located predominantly in a ring of radius 250 pc, also seen later in CO (Nakai et al., 85 IAU Symp 115; Lo et al., 87 ApJ 312 574). Studies of isotope ratios (Richard and Blitz 85 ApJ 292 L57; Young and Sanders 86 ApJ 302 680), which show a range of values for 13CO/CO, indicate that molecular masses derived assuming a constant CO/H_2 ratio are uncertain by a factor of 2.

<u>Extragalactic Masers</u> - In the past three years OH megamasers have emerged as a new phenomenon. They are OH 18 cm masers associated with the nuclei of active galaxies, and are over a million times more powerful than galactic OH/HII masers such as W3OH. Sixteen are now known primarily infrared galaxies, with enormous FIR luminosities (10^{11}-10^{12} $L_\odot$) and distinctive FIR colours. Systematic surveys based on these properties are underway at several observatories (Baan et al. 1985, ApJ 298, L51; Bottinelli et al. 1985, A&A 151, L7; Norris et al. 1986, MNRAS, 221, 51P; Schmeltz et al. 86 AJ, 92, 1291; Staveley-Smith, et al. 1987, MNRAS 226, 689). Early work has been reviewed by Baan 1985 (Nature 315, 26), but more recent results are available only as preprints and IAU Telegrams (Circulars 4106, 4231, 4248, 4268, 4357, 4362). Models of megamasers are heavily weighted towards the prototype IC4553=Arp 220, for which there are detailed radio optical and infrared data (Norris et al. 1985, MNRAS 213, 821 and 216, 701; Scoville et al. 1986, ApJ 311, L47; Baan et al. 1987, ApJ 313, 102). Excited OH at 5 cm has been detected in absorption IC4553 by Henkel et al. 1986 (A&A 168, L13), who discuss a possible FIR pump for megamasers.

Intermediate between normal masers and megamasers are the OH masers in the starburst galaxies M82 and NGC253. These have been mapped using the VLA by Weliachew et al. 1984 (A&A 137, 335) and Turner 1985 (ApJ 299, 312). NGC253 is unique in showing OH maser emission in all four 18 cm lines from extended regions over a kiloparsec in size. M33 was searched unsuccessfully for OH masers by Fix & Mutel 1985 (AJ 90, 736) using the VLA. It is still hard to detect normal OH masers in extragalactic systems.

H_2O masers are rather easier to detect. New extragalactic H_2O masers have been reported by Claussen et al. 1984 (Nature 310, 298), Henkel et al. 1984 (A&A 141, L1), Haschick & Baan 1985 (Nature 314, 144), Henkel et al. 1986 (A&A 155, 193) and Whiteoak & Gardner 1986 (MNRAS 222, 513). The most luminous extragalactic H_2O masers are less than 1000 times as powerful as the galactic source W49. They present a challenge to the theoretician because of their compact sizes (Claussen & Lo 1986, ApJ 308, 592), which constrain pump schemes.

<u>Extragalactic Hydrogen</u> - Thousands of galaxies have now been observed with the large single dishes of Arecibo, Green Bank and Effelsberg. Such data is widely used to study the dependence of properties of galaxies on environment (Haynes et al. 84 Ann. Rev.AA 22, 445; Helou et al. 84 ApJ Suppl 55, 433; Hoffman et al. 85

ApJ 289, L15; 87 ApJ Suppl 63, 247; Giovanelli and Haynes 85 ApJ 292, 404; 86 ApJ 306, 466; Williams and Rood 87 ApJ Suppl 63, 265; and several publicaitons in "Clusters and Groups of Galaxies" 84 Ap & Sp Sci Lib vol 111 and "The Virgo Cluster of Galaxies" 85 ESO Workshop no 20). The evidence that galaxies lose part of their HI disk through stripping in the cores of the denser clusters is quite clear now (see also Warmels, 86 PhD Thesis, University of Groningen) and simple orbit analyses (Dressler 86 ApJ 301, 35; Giraud 86 AA167,25) seem to support this.

Several large surveys have been used to extract information about the clustering of galaxies on large scales (Giovanelli et al 86 ApJ 300, 77 and 86 AJ 92, 250; Bicay and Giovanelli 87 AJ 93, 1326) revealing a very filamentary structure of the universe. The regions devoid of galaxies have been looked at but no HI has yet been found (Krumm and Brosch 84 AJ 89, 1461, Hulsbosch 87 AA Suppl 69, 439).

In particular the VLA has contributed to studies of the faint HI emission in Elliptical galaxies (Appleton et al. 85 MNRAS 217, 779; van Gorkom et al. 86 AJ 91, 791; Lake et al. 87 ApJ 314, 57) in addition to continued studies with the WSRT (Knapp and Raimond 84 AA 138, 77; Sancisi et al. 87 ApJ 315, L39). A variety of HI morphologies appear: rings, disks and asymmetric distributions. The general impression is that HI is more abundant in low luminosity systems and that there is more HI than can be accounted for by stellar mass loss. The latter suggests an external origin for the HI such as capture of small, gas rich systems.

The ring distributions are very reminiscent of the HI found in SO galaxies, where both very small and very extended HI rings have been found (van Driel 87 PhD Thesis, Univ. of Groningen; Bajaja et al.84 AA 141, 309; Krumm et al. 85 AA 144,202; Knapp et al. 85 AA 142, 1; Gottesmann and Hawarden 86 MNRAS 219, 759; Shostak 87 AA 175, 4). In addition several more SO galaxies with polar rings have been observed (van Gorkom et al. 87 ApJ 314, 457). HI in these objects is associated with the polar rings, which appear to be stable, rotating structures.

Studies of individual galaxies made with the VLA and WSRT include large, nearby galaxies (M31: Brinks and Burton 84 AA 141, 195; Brinks and Bajaja 86 AA 169, 14; Walterbos and Schwering 87 180, 27; M33: Deul and van der Hulst 87 AA Suppl 67, 509; NGC 6946: Tacconi and Young 86 ApJ 308, 600, NGC 55: Hummel et al. 86 AA 166, 97) and several peculiar or interacting systems (NGC 1023: Sancisi et al. 84 MNRAS 210, 497; NGC 3718: Schwarz 85 AA 142, 273; NGC 4725/47 Wevers et al. 84 AA 140, 125). Puzzling in the case of interacting galaxies remains the occurrence of large, outlying HI complexes like in Stephan's Quintet (Shostak et al. 84 AA 139, 15) or the Leo group of galaxies (Schneider et al. 86 AJ 91,13). These large "intergalactic" gas complexes are probably tidal debris, though a primordial origin cannot be ruled out entirely.

A few barred galaxies have been studied (Gottesmann et al. 84 ApJ 286, 471; Ball 86 ApJ 307, 453). There appears to be little promise for studying the kinematics of the bar using the HI line, often because of lack of detectable HI or lack of resolution in the bar region.

The question of dark matter in galaxies has received increased attention (see "Dark Matter in the Universe" IAU Symp. 117). The use of HI to determine the rotation curves of galaxies at large galactocentric radii is very important and a first detailed study of NGC 3198 (van Albada et al. 85 ApJ 295, 305) has been followed by studies of a large number of objects using data from the literature (Athanassoula et al. 87 AA 179, 23; Kent 87 AJ 93, 816). In general more than half the total mass of a galaxy appears to reside in a dark halo component. A study of binary galaxies where the orbital motion gives another estimate of the total mass confirms this picture (van Moorsel 87 AA 176, 13). A very massive, or at least fast rotating galaxy has been found by Giovanelli et al. 86 ApJ 301, L7.

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Detailed HI maps suggest the existence of a surface density threshold for star formation (Skillman 86 "Star Formation in Galaxies" NASA Conf. Pub. 2466, 263), and such a threshold phenomenon may have inhibited recent star formation in low surface brightness galaxies (van der Hulst et al. 87 AA 177, 63). A study of the star forming regions in a prominent spiral arm of M83 (Allen et al. 86 Nature 319, 296) suggests that if the density wave picture holds molecular clouds must dissociate on a kpc large scale.

Active and low redshift QSOs have also been studied in HI in the past few years. HI emission in QSOs is faint but detectable (Bothun et al. 84 AJ 89, 1293; Condon et al. 85 AJ 90, 1642; Hutchins et al. 87 AJ 93, 2) and suggests HI properties similar to normal spiral galaxies, supporting the idea that QSOs live in normal host galaxies. HI absorption in the direction of active nuclei (Dickey 86 ApJ 300, 190) suggests inflow of HI into the active nucleus in a number of objects and the presence of rotating systems, probably disks (Haschick and Baan 85 ApJ 289, 574). Wolfe et al. reported HI absorption at a very high redshift of $z = 2.04$, possibly originating in a distant galactic disk. Searches for redshifted HI have not been very successful thus far (de Waard et al. 85 AA 145, 479).

<u>The Microwave Background Radiation</u> - *Spectrum*. Substantial progress on measuring the detailed spectrum of the microwave background radiation has been achieved through careful radiometric measurements at centimetre wavelengths (De Amici et al., 1985, Astrophys. J., 298, 710; Mandolesi et al., 1986, Astrophys. J., 310, 561; Witebsky et al., 1986, Astrophys. J., 310, 145; Johnson & Wilkinson 1986, Astrophys. J., 313, L1; Smoot et al., 1987, Astrophys. J., 317, L45), through bolometric work from balloons at millimetre wavelengths (Peterson et al., 1986, Phys. Rev. Lett., 55, 332), and through improved measurements of optical transitions of CN molecules (Meyer & Jura 1985, Astrophys. J., 297, 119; Crane et al., 1986, Astrophys. J., 309, 822; Mandolesi et al., 1986, IAU Symposium 124, 59). These results are consistent with a temperature $T_r = 2.74$ K from 20 cm to 1 mm. The deviations from a black-body spectrum reported in 1981 (Woody & Richards, Astrophys. J., 248, 18) have not been confirmed. To an accuracy of better than five per cent, there are no spectral distortions in the background radiation over this wavelength range. This fact severely constrains events causing large energy releases in the early Universe and non-standard models of the origin of the background radiation.

Polarization. Linear polarization in the microwave background radiation may be caused by anisotropic expansion of the Universe near epochs of substantial ionization. On scales >7° there have been no improvements to the limits of about 0.2 mK on linear polarization measured by Lubin et al., (1983; Astrophys. J., 273, L51).

Dipole and Quadrupole Anisotropy. Re-analyses of data taken earlier by Halpern (1986; IAU Symposium 124, 63) and Lukash & Novikov (1986; IAU Symposium 124, 73), and the newer data of Lubin et al., (1985; Astrophys. J., 298, L1), are consisent with a dipole anisotropy of amplitude 3.3 mK oriented towards $\alpha = 11^h$, $\delta = -7°$. There is no significant evidence for any quadrupolar anisotropy > 0.2 mK, or any higher-order terms in these data. These results are interpreted in terms of a 370 kms^{-1} motion of the local system of rest. Lubin et al.'s data show the expected 30 kms^{-1} annual modulation of the dipole anisotropy caused by the motion of the Earth around the Sun.

Anisotropies on scales 1° - 60°. Sensitive measurements of the anisotropy of the microwave background radiation on scales >2° have been made by Davies et al., (1987; Nature, 326, 462). These data indicate the possible detection of intrinsic fluctuations of about 0.16 mK on intrinsic scales of about 4°. Results from the

Prognoz 9 satellite (Lukash & Novikov 1986; IAU Symposium 124, 73) indicate correlated fluctuations less than 0.07 mK on scales above 20°. Mandolesi et al. (1986; Nature, 319, 751) found limits of 2 mK for fluctuations on scales of 2°-10°. This homogeneity of the Universe on scales larger than the horizon at recombination has been used as evidence for inflationary models of the Universe.

Anisotropies on scales 1' - 1°. Scales <20' are amenable to single-dish observations of the background radiation, and a number of useful measurements of limits to fluctuations are available on arcminute scales. The recent measurements by Uson & Wilkinson (1984; Nature 312, 427) and Readhead et al., (1987; private communication) limit fluctuations on angular scales 5' to 15' to be less than about 0.1 mK. the absence of such fluctuations is becoming an embarassment to many theories of the formation of galaxies and clusters of galaxies, unless the Universe went through a late, quiescent, hot, phase in which early fluctuations were erased, or unless the Universe contains large quantities of non-baryonic matter.

Anisotropies on scales less than 1'. Observations with interferometers provide the only limits to the fluctuation amplitudes on the smallest angular scales. Fomalont et al., (1984; Astrophys. J., 277 L23), and Knoke et al., (1984, Astrophys. J., 284, 479) achieved limits to the fluctuation amplitude of about $1(\theta/\text{arcmin})^{-1}$ mK on angular scales of 0.1 - 1 arcmin. Kellermann et al., (1986, Highl. Astron., 7, 367) reported the tentative detection of fluctuations at a level 0.13 mK on a scale of 1 arcmin and 0.54 mK on a scale of 0.3 arcmin. More recent observations (Martin & Partridge 1987, Astrophys. J., in press; Fomalont & Kellermann 1987, Astrophys. J., in press) have achieved higher sensitivities, and limit the fluctuation amplitudes to be less than 0.12 mK on scales of 1 arcmin, and less than 0.5 mK on scales of 0.3 arcmin. On these sub-arcminute scales, fluctuations related to galaxy formation by shocks might appear.

The Sunyaev-Zel'dovich effect. Reliable detections of the Sunyaev-Zel'dovich effect, the changes in the temperature of the background radiation caused by its passage through the hot gas in clusters of galaxies, have now been reported, with two independent groups working at 1.5 cm reporting consistent detections at the level of about 0.3 mK towards several clusters of galaxies (Birkinshaw 1986, Green Bank Workshop, 16, 261; Uson 1986, Green Bank Workshop, 16, 255). Preliminary data on the angular sizes of the effects in a few clusters are also available. Attempts to detect the effect at millimetre wavelengths (e.g. Chase et al., 1987, Mon. Not. R. astr. Soc., 225, 171) have, as yet insufficient sensitivity.

A variety of other effects, such as cosmic strings and moving gravitational lenses, are also expected to produce signals in the microwave background radiation. These effects are generally too small to be observationally interesting, although the absence of an anisotropy near the candidate lensed double quasar 1146+111B,C has been used to argue against its interpretation as the effect of a cosmic string (Stark et al., 1986, Nature, 322, 805; Lawrence et al., 1986, Astr. J., 92, 1235.

In summary, the microwave background has an accurately thermal spectrum, is not strongly polarized, and is largely isotropic. The 0.1 per cent dipole anisotropy is interpreted in terms of motion of the local system of rest, and shows annual variations caused by the orbital motion of the earth, but no quadrupolar anisotropy has been found. On smaller angular scales the radiation field remains remarkably isotropic, although there are tentative indications that structures of cosmological origin may be appearing, and the Sunyaev-Zel'dovich effect appears to have been detected.

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