NATIONAL RADIO ASTRONOMY OBSERVATORY

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December 10, 1984

Dear ~~Colleague~~: alan.

Enclosed is a draft of the Commission 40 report to which you kindly contributed. In the process of organizing the report, your contribution may have been split into more than one section, and subject to additions, subtractions, or changes.

Please let me know if there are any errors or emissions in the current version which you would like to see changed. I am particularly interested in your comments on your own contribution, but would welcome comments on any part.

I am supposed to send the manuscript to the General Secretary by January 1, and I intend to do this. So it would be most helpful to have your reply before then, although I realize that the impact of the holiday season may preclude this. Therefore I intend to submit a revised version in mid-January with the hope that it can still be used.

Sincerely,

Ken

K. I. Kellermann

KIK/bbs
Enc.

Thanks for the nice job!

NRAO-85/14

Report of Commission 40

International Astronomical Union

K. I. Kellermann
National Radio Astronomy Observatory*

Alan thanks for what is the longest and most comprehensive contribution. Ken

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Reports on Astronomy

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PRESIDENT: K. I. Kellermann

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ORGANIZING COMMITTEE: J. G. Ables, N. Broten, G. Dulk, B. Hoglund, N. Kardashev, M. Morimoto, S. Okoye, G. Setti, R. Strom, G. Swarup, L. Weliachew, T. Wilson, S. Wang.

The last triennium marked the 50th anniversary of the paper describing the first observations of cosmic radio emission by Karl Jansky in 1933. Sullivan (82 *Classics in Radio Astronomy*, Reidel) has published a collection of the major historical papers in radio astronomy, and collections of papers discussing the historical development have been published by Sullivan (84 *Early Years of Radio Astronomy*, Cambridge Univ. Press) and by Kellermann and Sheets (84 *Serendipitous Discoveries in Radio Astronomy*, NRAO).

The following symposia of interest to radio astronomers were held during the period under review or their proceedings were published during this period.

IAU Symposium No. 97, Extragalactic Radio Sources, August 1981, (eds.) D. S. Heeschen and C. M. Wade, Reidel, 1982.

IAU Symposium No. 100, Internal Kinematics and Dynamics of Galaxies, Aug. 1982, (ed.) E. Athanassoula, Reidel, 1983.

IAU Symposium No. 104, Early Evolution of the Universe, Aug./Sept. 1982, (eds.) G. O. Abell and G. Chincarini, Reidel, 1963.

IAU Symposium No. 108, Structure and Evolution of Magellanic Clouds, Sept. 1983, (eds.) S. van den Bergh and K. S. de Boer, Reidel 1984.

IAU Symposium No. 109, Astrometric Techniques, Jan. 1984, Reidel.

IAU Symposium No. 110, VLBI and Compact Radio Sources, June 1983, (eds.) R. Fanti, K. Kellermann, G. Setti, Reidel, 1984.

10th Texas Symposium, Dec. 1980, ed. R. Ramaty and F. D. Jones, New York Acad. Sci, 1981.

11th Texas Symposium, Dec. 1982, ed. D. S. Evans, New York Acad. Sci., 1982.

Green Bank Workshop on the Comparative HI Content of Normal Galaxies, April 1982, (eds.) M. Haynes and R. Giovanelli, NRAO.

Green Bank Workshop on Low Frequency Variability of Extragalactic Radio Sources, April 1982, (eds.) W. D. Cotton and S. R. Spangler, NRAO.

Green Bank Workshop on Interference Identification and Excision, Sept. 1982, (eds.) W. Erickson and R. Fisher, NRAO.

Bangalore Winter School on Energetic Extragalactic Sources, Tata Inst. 1983.

Symposium on Astrophysical Jets, (ed.) A. Ferrari and A. Pacholczyk, Reidel, 1983.

Astrophysical Cosmology, Vatican Study Week, Oct. 1981, (ed.) H. Brück, G. Coyne, and M. Longair, Pontifical Acad. Sci., 1982.

Quasars and Gravitational Lenses, 24th Liege Colloquium, June 1983, (ed.) J. P. Swings, Univ. Liege, 1984.

URSI Symposium on Indirect Imaging, (ed.) J. A. Roberts, Camb. Univ. Press, 1984.

IAU Symposium No. 112, The Search for Extraterrestrial Life, (ed.) M. Papagiannis, Reidel, Boston, June 1984.

QUASAT Workshop, Vienna, Austria, June 1984, ESA-SP 213.

Green Bank Workshop on Millisecond Pulsars, (eds.) S. P. Reynolds and D. R. Stinebring.

This report follows the style of recent Commission 40 Reports. The following commission members have contributed to the report: Instrumentation and Techniques (Baldwin, Booth, Cornwell, Shaffer, Weinreb, Weliachew); Solar System (Berge, Dulk); Continuum Research (Bridle, Fanti, Hjellming, Kapahi, Lo, Pauliny-Toth, Strom, Wielebinski); VLBI (Cohen); Pulsars (Backer); Molecular Spectroscopy (Reid, Wilson); HI and HII Research (Haynes, Shaver, van Gorkom); SETI (Papagiannis).

INSTRUMENTATION

Aperture Synthesis Radio Telescopes - The last three years have seen very active developments with several proposals for new telescopes or substantial modifications of existing ones, construction starting on new approved projects, completed instruments being brought into commission, and important improvements in the frequency coverage, sensitivity and image quality of well-established telescopes. The principal new developments not discussed in other sections are summarized below.

Australia - The Australia Telescope (Poulton 84 IAU/URSI Symp Indirect Imaging 67) for which funding was approved in November 1983 will be the most important high resolution radio telescope in the southern hemisphere for many years. It has two main components: (i) a compact array at Culgoora comprising six 22m antennas on a 6 km baseline of which five are movable on a 3 km rail track and (ii) a long baseline array obtained by correlation of signals between the compact array, a new 22m antenna near Siding Spring mountain and the Parkes 64m telescope. It is also planned to use AT in collaboration with other antennas. Important features of the design include rapid changing of the frequencies of operation, very broad receiving bandwidths, and good polarization and spectral capabilities. A large amount of design and development work has been finished and completion is planned for 1988. Initial operation will be at four bands between 1.4 and 10 GHz with extensions to several other bands between 327 MHz and 115 GHz in the longer term.

The Molonglo Observatory Synthesis Telescope (MOST) (Mills 81 Proc Ast Soc Aust 4, 402) has been in operation at 843 MHz giving full synthesis mapping over 23' x 23' cosec δ fields of view with a resolution of 43" x 43" cosec δ and an rms noise sensitivity of 0.2 mJy in 12h.

Regrettably, operation of the Culgoora radio heliograph came to an end in 1983.

Canada - The frequency range of the four-element synthesis telescope at DRAO, Penticton has been extended to cover operation at 408 MHz as well as the original 1420 MHz band.

India - The Ooty Synthesis Radio Telescope (OSRT) at Ootacamund has been commissioned and produced its first astronomical results (Swarup 84 JAA 5, 139). The combination of the Ooty Radio Telescope and seven smaller antennas distributed over an area of 4km x 2km gives a coverage of about ±40° in δ with a resolution of 40" x (50-90)" over a field of view of 3° x 0°.6 and an rms noise of about 3 mJy in 10h integration.

The Gauribidanur T array operating at 34.5 MHz has produced its first astronomical results (Dwarakanath et al. 82 JAA 3, 207) in studies of supernova remnants with a resolution of 26' x 40'.

A proposal for a Giant Metre Wavelength Radio Telescope (GMRT) has been put forward (Swarup 84) with the aim of providing very high sensitivity observations at low frequencies with angular resolutions ranging from 4" at 610 MHz to 75" at 38 MHz. The proposed elements are 34 cylindrical antennas spaced over a 3 km radius with a total collecting area of $65000 m^2$. The projected date for completion is 1992.

Netherlands - The Westerbork Synthesis Radio Telescope (WSRT), operational on a 2.7 km baseline since 1980 has extended its frequency range to include 327 MHz with observations starting in December 1983.

United Kingdom - The Multi Telescope Radio Linked Interferometer (MTRLI) at Jodrell Bank, magically transformed into MERLIN in about 1982, has extended its observations to 5 GHz and 22 GHz for three of the antennas. Future plans include operation at 151 MHz in 1984-5 and incorporation of an antenna at Cambridge.

The Cambridge Low Frequency Synthesis Telescope (Baldwin 84 reported at URSI Gen. Assembly), comprising 60 steerable Yagi arrays on a 4.6 km east-west baseline, has been commissioned. Operating initially at 151 MHz it gives 70" resolution over 5°-10° fields of view with an rms noise sensitivity of 20 mJy in 12h. The former 6C array has been operated at 38 MHz to give 16' x 16' mapping of the sky for $\delta \geq 65°$. The 5 km Telescope has made use of small (9m) increments in baselines for studies of large sources at 15 GHz.

U.S.A. - The Very Large Array (VLA) near Socorro, New Mexico (Napier et al. 83 Proc IEEE 71, 1295) has established its position as the most powerful existing radio telescope. The successful development of self-calibration techniques combined with its very high sensitivity has led in the last three years to the most detailed radio maps of sources yet made; r.m.s. noise levels of 100 μJy can be reached in only 10 minutes and sources as weak as 50 μJy have been catalogued. Operation at 327 MHz is planned for 1985, and a 75 MHz system has been proposed.

The Clark Lake Teepee Telescope (Erickson et al. 82 ApJ Sup 50, 403) has been in regular use for solar, galactic and extragalactic programs.

U.S.S.R. - The Siberian Solar Radio Telescope sited near Irkutsk has started astronomical observing. The telescope, composed of 128 2.5m antennas on each of two axes about 600m in length operates at 5.8 GHz with a bandwidth of 120 MHz.

P.R. China - The Miyun synthesis telescope, Beijing Observatory, was put into service in October 1984. This is a 16 x 12 element E-W array spanning 1164 metres, and at present, working at 232 MHz. The synthesis pattern gives a resolution of 3'.8 x 3'.8 csc δ. A polar region "dirty map" obtained in 2 x 12 hours shows a dynamical range of 100:1, where sources of 0.2 Jy are easily detected. The thermal noise-limited sensitivity of the system is about 0.05 Jy. With a field of view of 8° x 8°, it will be used for source survey of sky region $\delta \geq +30$ and a number of other astronomical programmes.

Millimeter Telescopes - After R. B. Leighton's pioneering work on high precision 10.4 m antennas, larger telescopes are now being built or put into operation. The 45 m antenna at Nobeyama, Japan, operates at 3 mm wavelength with an aperture efficiency around 30% and the IRAM 30 m antenna is being tested near Granada, Spain (83 Baars, Infrared and mm Waves 9, 241, Academic Press). A second 30 m antenna is being completed by the Iraq Council for Scientific Research at a 2100 m site on Mt. Koerk and is expected to be operational in 1985.

Progress has been made in surface panel manufacturing, thermal stability or control and surface measurements. Surface panels are now being manufactured with accuracies around 0.05 mm, mostly through molding techniques applied to panels composed of aluminum honeycomb with aluminum or carbon fiber skins. More attention has been given to thermal deformations of surfaces and structures. Greater stability has been achieved by careful design of steel structures and associated thermal control, or through the use of carbon fiber. Examples of later include Nobeyama for the surface panels, and the 15 m antennas of the IRAM interferometer for the surface panels and the back-up structure. Because most radio sources are weak at mm wavelengths, millimeter antennas are made as large as possible, and, thus, have very large apertures in units of wavelengths compared to cm and dm telescopes. For this reason, pointing of their beams - usually less than one arc min - is difficult, especially in the presence of even moderate winds. This may be the ultimate limiting factor in the use of large single dish millimeter telescopes. Pointing with arc sec accuracy requires structures with high resonant frequencies and complex servo-systems. Surface measurements, another critical task, have become more straightforward by the use of radio holography which has been successfully applied to the Green Bank 140-ft, the Kitt Peak 11 m, the Bonn 100 m, the Parkes 64 m, and the RATAN 600 radio telescopes. Measuring and adjustment techniques are often the limiting factor in the surface accuracy of mm telescopes and it is good to have a surface quality test by direct radio astronomical means. For example, with the high accuracy of structure and panels, future improvements of the surface accuracy are probably possible for the Nobeyama 45 m telescope and the 30 m telescope in Spain.

The surface and the back-up structure of the 36-ft telescope on Kitt Peak, Arizona, have been completely refurbished providing an aperture efficiency of 30% at 230 GHz for what has now become a 12 m antenna (84 Gordon, Sky and Telescope 67, 326). Holographic and mechanical surface measurements indicate an rms surface accuracy of 75 microns. Construction proceeds on Mauna Kea of a 15 m telescope funded by the UK and the Netherlands. The design goal of this telescope is to operate it as a diffraction-limited telescope down to 0.8 mm wavelength. Another telescope of 10.4 m will also be erected on Mauna Kea. It will be an improved version of the Owens Valley antennas with acceptable performance in the sub-mm range. A 10.4 m telescope of the same design is being built by the Raman Institute in Bangalore, India. A 13.7 m ESSCO telescope is being constructed at a 3000 m site in the Chaidamu Basin, China for the Nanjing Observatory. Completion is expected by 1986. Finally, a 10 m telescope for the mm and sub-mm range is planned on Mount Graham, Arizona (Baars et al. 84 SPIE 444, 65) as a joint project of the Max-Planck Institute and the University of Arizona.

After the two element interferometer at Hat Creek, the first of its kind, the Owens Valley interferometer has started operating in 1982/83 (Masson et al. 84 ApJ 283, L37). It is composed of three 10.4 m antennas equipped with SIS receivers in the 3 mm band. The surface quality of these antennas allows operation at shorter wavelengths. The interferometer is capable of a few arc sec resolution and is equipped with filter spectrometers. The Nobeyama interferometer, with five 10 m antennas, has been tested at 1.35 cm and will begin operation near 3 mm in the winter 84/85. The three-antenna IRAM interferometer with 15 m antennas is under construction at an elevation of 2550 m in Southern France. The design goal of this instrument is operation in the short mm range. Plans are being developed in the USA for a large millimeter array.

Receivers - Considerable progress has been made over the past years in receiver sensitivity. Low-noise, cryogenically-cooled, gallium-arsenide, field-effect amplifiers (GASFET's) have been widely used for cm-wave radio astronomy receivers. Noise temperatures of < 10K at 1.5 GHz (Weinreb 82 IEEE Trans. on MTT, MTT-30, 849) and 27K at 10.7 GHz (Tomassetti, et al. 81 Electronics Lett. 17, 949) have been reported. Lower noise temperatures are now being measured in various laboratories utilizing high electron mobility transistors (Berenz, et al. 83 IEEE Mic. and Millimeter Wave Monolithic Circ. Symp., Digest of Papers, IEEE #84CH2042, San Francisco). Low noise 22 GHz maser radiometers are now in routine use on the Green Bank, OVRO, Haystack, and Bonn antennas with zenith system temperatures as low as 50K under good sky conditions. The Green Bank 140-ft antenna is equipped with 3 upconverters to give nearly complete coverage of the range 5 to 25 GHz with system temperatures in the range 35 to 80K. A cooled GASFET amplifier gives system temperatures under 25K over the range 1.3 to 1.8 GHz.

Receiver temperatures near 100K DSB have been reached at 3 mm wavelength over large frequency ranges with mixers based on Schottky barrier diodes (Predmore et al. 84 IEEE Trans, MTT-32, 498; Archer and Faber 84 Int J Infrared and mm Waves 5, 1069). Another type of non linear device, the superconducting SIS junction has now come of age (Phillips and Woody 82 Ann Rev AA 20, 285). Here, the tunneling of quasiparticles through a composite thin-film device gives rise to a sharp non-linearity at very small I-V products, that is at very small local oscillator powers. With SIS junction mixers, receiver noise temperatures below 100K DSB near 3 mm (Linke et al. 83 ApJ 271, L85) and below 300K DSB at 1.3 mm (Sutton et al. 83 ApJ 275, L49) have been achieved, both during actual observations on telescopes. Depending on junction fabrication, it may be an advantage to cool those devices down to 2-3 K. This is often done with hybrid cryostats where cooling to such temperatures is obtained from a combination of commercially available refrigerators and refillable He containers (Blundell et al. 82 Int J Infrared and mm Waves 3, 793).

Sources of power for local oscillators are now generally solid state Gunn oscillators followed by frequency doublers or triplers. This is much cheaper in operation cost and more reliable than the previously used klystrons. As a consequence, mm receivers are now progressively becoming pure solid state systems, even at short wavelengths (Archer 82 IEEE Trans., MTT-30, 1247).

Acousto-optical spectrometers (AOS) have now become stable enough to be used in position switching mode on large telescopes (Masson 82 AA 114, 270). Such devices are now routinely used at Yunnan, Nobeyama, RATAN 600 and Owens Valley for single-dish observations. In Nobeyama, a 2 GHz band is analyzed into 16000 elements by eight 250 MHz AOS's and a 160 MHz band can also be analyzed into 4000 channels by four 40 MHz AOS's. At Owens Valley, bands of 100 MHz and 500 MHz are analyzed into 1024 and 512 channels respectively. The millimeter interferometer in Nobeyama has a spectrometer of a novel design (Chikada et al 83 URSI/IAU Symp on Measurement and Processing for Indirect Imaging). This system samples the signals from the individual antennas and Fourier transforms them before performing the antenna products in frequency space. This is in contrast to the usual approach of cross correlation interferometry. This spectrometer uses IC's performing real time FFT's. The present version has 80 MHz bandwidth, and will be extended to 320 MHz. This approach appears to be more cost-effective for the same performance than the usual cross correlation method. Multibit FFT spectrometers with bandwidths up to 10 MHz are in use at JPL, Harvard, and Stanford; and the technology is being extended to 40 MHz with spectrometers under design and construction at NRAO and Cornell.

VLBI Systems and Programs - During the past triennium the dynamic range of VLBI maps has improved dramatically with the use of larger numbers of antennas and more sophisticated calibration procedures. Five to eight antennas are commonly used, and an 18-antenna experiment was successfully conducted in 1984. A dynamic range of 100:1 is now common, and several hundred to one is expected soon. Another major improvement is the inclusion of the VLA, or Bonn 100 m, telescopes with global fringe fitting techniques to dramatically improve the sensitivity. Sources as weak as 20 mJy have been mapped at 5 GHz with a resolution of 0".001. More than 30 different radio telescopes are being used in VLBI observations at wavelength ranges from 3 mm to 1 meter. Major international collaborations are common with more than 16 different countries on all continents being involved in VLBI research.

The major organized VLBI networks which schedule regular observations are those in the USA and Europe. Active telescopes in the U.S. Network are: Fort Davis (Texas), Green Bank (West Virginia), Hat Creek (California, North Liberty (Iowa), Haystack (Massachusetts), and Owens Valley (California). Also used regularly as part of the network are Effelsberg (W. Germany) and the VLA (New Mexico) and Maryland Point (Washington, D.C.). Other affiliate observatories are Algonquin Park (Canada), Arecibo (Puerto Rico), and the NASA DSN stations. The European VLBI Network (EVN) uses: Onsala (Sweden), Effelsberg (W. Germany), Westerbork (Holland), Jodrell Bank (U.K.) and Medicina (Italy). Torun (Poland) and Crimea (U.S.S.R.) are also regularly used. The new 32 m telescope in Medicina is dedicated to VLBI use as will be a similar telescope planned for Noto (Siracusa) in Sicily. Details of the antennas, instrumentation and procedures are published in the Network handbooks: U.S. Network Handbook (ed.) D. C. Backer, University of California, Berkeley, and EVN Handbook (ed.) R. S. Booth, Onsala Space Observatory, Sweden, both available from the editors. Combined Network operation, so-called "Global" Network experiments are conducted on a regular basis. Australian, South African, and US antennas have been linked to study southern hemisphere sources (Preston 82, IAU Symp. 110, eds. Fanti et al.). A Germany-China baseline at 1430 MHz was successfully utilized (Wan 82 Acta Astron. Sinica 23, 376). A 5-station 327 MHz experiment involving Ooty (India) with Torun, Crimea, Westerbork and Jodrell Bank gave fringes. Hartas et al. (83 M.N.R.A.S. 205, 625) have used the Cambridge 3.6 Hectare Array at a frequency of 81.5 MHz together with a portable outstation on 11 baselines from 0.5 to 1500 km to investigate the feasibility of mapping sources with sub arcsec resolution at metre wavelengths. A three-antenna VLBI system is operating in the USSR with 20 m antennas in Crimea and Serpekhev and the new 70 m antenna at Evpatorly (83 Soviet AJ 83, 219). Additional antennas at Medvezhii Osera (64 m), Ulan Ude (25 m), and Usuriisk (70 m) will be added in 1985, and will be equipped with MKII recording systems.

Recording Systems - Although the MKII recording system (Clark 73, Proc IEEE 61, 242) is regularly used, there is considerable pressure on the MKIII system (Rogers et al. 83 Science 219, 51) but its use is limited by the high consumption of tape. This wideband system runs through a single tape in about 13 minutes at 112 Mbps, but a greatly improved recording density is now possible using a narrow track movable headstack to record 28 40-micron wide tracks in each of 16 multiple passes on a single tape. The bit density is approximately 10 Mbits/square inch and represents a more than 10-fold improvement over the original MKIII. Existing recorders will be upgraded to the higher bit density. A Mark III compatible system (K3) has been developed in Japan (Saburi et al. 82, Proc IAG Symp No. 5, 307).

VLBI Processors - MKII VLBI processors are available at NRAO, Charlottesville, and MPI Bonn, both with 3 stations spectroscopic capability and at Caltech, Pasadena (5 stations continuum only). Three-station MKIII processors are in operation at Haystack and Bonn, and Caltech will soon complete a 5-station MKIII processor which will be operational in 1985 and will allow single pass, 16-station MKII processing. A 2-station MKII processor is being built in the USSR.

New VLBI Projects - A start was made in 1984 on a major new project--a dedicated array of ten 25-m telescopes to be built at sites throughout the United States from Hawaii to Puerto Rico spaced so as to provide good u-v plane coverage and hence excellent image quality. This system, the VLB Array (Kellermann 84, IAU Symp 110, 377) will have a wavelength range from 0.7 to 90 cm with full polarization capability. Bandwidths will be at least 56 MHz giving an r.m.s. noise of 0.05 mJy in an 8-hour integration time. For spectroscopic use, up to 512 frequency channels will be available. As many as 19 tapes will be simultaneously replayed, to allow up to 9 non VLBA antennas to be used to further increase the sensitivity and resolution. Studies on the Canadian VLB Array have continued (Legg 84, IAU Symp 110, 383) and the current proposal contains two options: the original array of nine 32 m antennas and a more limited 4-element array (Seaquist 84, Proc. Workshop on QUASAT, ESA SP-213, p. 127). A combination of either array with the US or European Networks will fill important gaps in the baseline plane. A study of a 103-MHz 3-element VLBI Array in India has also been reported (Bhonsle 84, IAU Symp 110, 391).

After the first successful millimeter VLBI experiment at 3.4 mm wavelength, with a baseline of 140 million wavelengths (Readhead et al. 83 Nature 303, 504), more experiments have yielded positive detections even on baselines of 10^9 wavelengths on the quasar 3C273. Coherence times of several hundreds of seconds have been observed. For the first time in astronomy, this practically opens up the possibility of resolutions $\sim 10^{-4}$ arcsec.

Space VLBI - During the past three years much attention has been focussed on a study of a satellite-borne antenna for extending VLBI baseline (Burke 84, IAU Symp 110, 397) and culminating in a design study for a joint ESA-NASA mission - QUASAT (Schilizzi et al. 84, IAU Symp 110, 407, ESA SP-213). QUASAT will be a 15 to 20 m antenna in low Earth orbit and will be used to extend currently available baselines by a factor of about 3 at 1.35, 6 and 18 cm. By observing simultaneously with the ground arrays, the relative motion of QUASAT and the Earth provides for exceptionally dense coverage of the aperture plane of the interferometer system. This system will give superb image quality (Readhead et al. 84, ESA SP-213, 101). Soviet Space VLBI missions are also being planned. Two experiments are under consideration. The first will put a 30 m antenna into an orbit with a height of about 500 km while the second considers a much larger orbit of one million km (Sagdeev, ESA SP-213, 19).

Image Processing Techniques - A timely overview of recent developments in astronomical image processing techniques is available in the proceedings of an IAU/URSI conference on "Indirect Imaging" held in Sydney in 1983 (ed. J. A. Roberts, CUP 1984). Since 1981, the main advance in processing techniques has been the widespread acceptance and use of self-calibration to dramatically improve the quality of images produced from radio interferometer data (Schwab 80 Proc SPIE 231, 18; Cornwell and Wilkinson 81 MN 196, 1097). At the heart of this technique lies the observation that calibration errors in an interferometer array arise mainly at the individual antennas, due to atmospheric or instrumental effects, while data is collected from all possible pairs of antennas. Thus, since effectively one has to solve for the sky brightness anyway by deconvolving the effects of incomplete sampling of the u,v plane, one may as well solve for the antenna based calibration errors as well. The dynamic range of self-calibrated images is limited by those effects not factorizable per antenna, such as receiver noise and bandpass problems (see Cornwell and Wilkinson, in the proceedings of the Sydney meeting, op. cit.). Most arrays now achieve dynamic ranges between 30 and 45 dB (peak/rms) on sufficiently strong sources. There is some contention whether or not instantaneous baseline redundancy is responsible for the further increase in dynamic range now achievable with WSRT (Noordam and De Bruyn 82 Nature 299, 597; Cornwell and Wilkinson op. cit.) but, unfortunately, there is as yet little firm evidence to support either view. We note, however, that the dynamic range of VLA maps, made without redundancy, is beginning to approach that of WSRT maps, made with redundancy.

In the early days of self-calibration, it was generally supposed that a point source somewhere in the field of view was required; subsequent experience with the VLA, MERLIN and VLBI has revealed this to be somewhat conservative and that, instead, sources as complex as SNR may be self-calibrated if the u,v coverage is reasonably complete (see e.g. Cornwell and Wilkinson op. cit.).

In an important extension to self-calibration, Schwab and Cotton (83 AJ 88, 688) have shown that one can also solve for antenna related delay and fringe rate offsets when finding fringes in VLB data. Such "Global Fringe Fitting" lowers the signal to noise required for fringe finding, and will work on sources with considerable structure. In radio-astronomical imaging, self-calibration is now very widely accepted and used, while reconstruction with amplitudes alone, although feasible (see e.g. papers in proceedings of Sydney conference, op. cit.), is too expensive in terms of integration time required to reach a given sensitivity. Reviews of self-calibration have been published by Pearson and Readhead (84 Ann Rev AA) and Cornwell and Wilkinson (op. cit.)

Considerable progress has been made in the deconvolution of images made with radio interferometric arrays. Variants of CLEAN, such as Cotton's MX program and the modified CLEAN algorithm (Steer, Ito and Dewdney 84 AA), adapted to particular circumstances have been introduced. Chen and Frater (Sydney conf. op. cit.) have developed a CLEAN variant ideally suited to parallel processing. Maximum Entropy methods are still quite controversial; new justifications abound (Gull and Skilling, Sydney conf. op. cit.) but the work of Narayan and Nityananda (e.g. Sydney conf. op. cit.) provides a pragmatic interpretation which most people seem to accept. Reasonably sophisticated numerical algorithms for calculating the Maximum Entropy solution in two dimensions have been developed (e.g. Burch et al. 83 Comp. Vision, Graphics and Image Processing 23, 113; Cornwell and Evans 84 AA in press) but an analytic solution would still be very useful. Nityananda and Narayan (83 AA 118, 194) have discussed the extension of MEM to polarization data, and San-Roma and Estalella (84 AA 133, 299) and Shevgaonkar (84 in press) have married MEM and self-calibration.

Image processing for single dishes advanced rapidly during the middle and late seventies (see e.g. the review of Wielebinski, proc. Sydney conf. op. cit.) mainly due to the efforts of the Bonn group, but has progressed very little during the eighties. It is reasonable to expect further refinements to multibeam methods when large multibeam systems are constructed. Also the combination of interferometers and single dishes needed for imaging at millimeter wavelengths should generate new problems and solutions.

The advances in image processing during the last decade have been the result of refinements in hardware, such as computers and correlators, software, in the form both of unified software systems such as AIPS and of specific algorithms, and in the ingenuity of the astronomer. It is to be hoped that all of these factors will continue to improve with time.

Astrometry and Geodetic Applications of Radio Interferometry - Radio interferometry is now routinely providing precise baseline and source position results. Summaries of equipment, techniques, and results from VLBI and connected interferometers appear in several proceedings: IAU Symposia nos. 109 and 110; *High Precision Earth Rotation and Earth-Moon Dynamics* (82 O. Calame, ed., Reidel); *Geodetic Applications of Radio Interferometry* (82 NOAA Technical Report NOS 95 NGS 24); *Proceedings of the Ninth International Symposium on Earth Tides* (82 E. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart); and *Very Long Baseline Interferometry Techniques* (82 CNES Colloquium, Toulouse). Astrometric and geodetic applications of a VLBI array are discussed in *Multidisciplinary Uses of the VLBA* (83, Natl. Acad. Press, Washington, DC).

An important contribution to improved results is the use of the J2000.0 system, which is a more consistent treatment of precession, nutation, aberration, earth rotation, etc. (Kaplan 81 USNO Circular No. 163).

The Mark III VLBI system has greatly advanced precision astrometry and geodesy, and is described by Rogers et al. (83 Science 219, 51). The very best source positions, from VLBI (Ma et al. 81 BAAS 13, 899; Fanselow et al. 84 AJ 89, 987; and Robertson, in IAU 109), have accuracies approaching 0".001, and define an internally consistent reference frame. Numerous optical positions, generally in the FK4 system, of radio sources and/or stars in their vicinity have been determined in efforts to align the optical and radio coordinate systems (Dick et al. 82 AJ 87, 1374; Harrington et al. 83 AJ 88, 1376; Clements 83 MNRAS 203, 861; de Vegt et al. AA 101, 191 and 113, 213; West et al. 81 AA Sup 46, 277; Froeschle et al. 82 AA 116, 89; and Costa et al. 83 AA Sup 51, 425. Argue et al. (84 AA 130, 191) have compiled a recommended list of sources for radio and optical comparison. Efforts are also underway to use radio stars to relate the two systems (Carrasco et al. 83 AA Sup 52, 279). The minor planets also show promise for these purposes (Johnston et al. 82 AJ 87, 1593).

The VLA has produced a large number of modest precision positions (about 0".05: Perley 82 AJ 87, 859) which are in good agreement with VLBI observations. The NRAO radio link interferometer was used by Kaplan et al. (82 AJ 87, 570) to measure 16 sources to about 0".01 - 0".03. These positions were among the first to appear in the J2000.0 system.

Lyne et al. (82 MNRAS 201, 503) used the MERLIN radio link system at 408 MHz to measure proper motions of pulsars at the 0".007 per year level, by referencing a pulsar to another source in the same primary beam. Similar referencing has been used with VLBI to measure the 30" distance between the quasars 1038+52A,B to about 5 and 15 micro-arcseconds at 3.6 and 13 cm respectively (Marcaide et al. 83 AJ 88, 1133).

Robertson (84 Proc. of International Symposium on Space Techniques for Geodynamics) and Shaffer (IAU 110) show the results of repeated VLBI baseline measurements. The Haystack-OVRO baseline is stable to well under 1 cm per year. The Westford-HRAS baseline has been measured almost 200 times, and the length results show a 2 cm rms scatter. Motions of a few cm per year have been measured along the San Andreas fault in southern California. Sovers et al. (84 JGR 89, B9, 7597) present a set of baselines measured between the antennas of the Deep Space Network.

Earth tides, and the Love numbers, have been determined by VLBI (Herring et al., Ninth Int'l Symp on Earth Tides). VLBI measurements of polar motion and

UT1-UTC compare favorably with other modern techniques. VLBI and connected interferometer results are heavily weighted into the BIH averages for these values (Robertson et al. 83 Nature 302, 509; Carter et al. 84 Science 224, 957). The earth rotation measurements show striking correlation with atmospheric angular momentum (the sum of global winds), and suggest that radio astronomy may someday help predict the weather!

SOLAR SYSTEM RESEARCH

The Sun - Radio images of the quiet sun of unprecedented quality have been obtained using Westerbork (Chiuderi Drago et al. 77 AA 60, 277), Arecibo (Lang and Wilson 83 AA 127, 135) and the VLA (Dulk and Gary 83 AA 124, 103). Magnetic fields cause circular polarization of bremsstrahlung radiation from active regions and gyroresonance emission from hot spots (Felli et al. 81 ApJ 247, 325).

Progress has been achieved toward understanding plasma radiation from electron streams, shock waves and coronal transients, both from observations and theory (Stewart et al. 82 AA 116, 217; Vlahos et al. 82 ApJ 258, 812; Kerdroan et al. 83 ApJ 265, L19; Gary et al. 84 AA 134, 222; Bougeret et al. 84 Solar Phys 90, 401; reviews by Melrose 81 Proc ASA 4, 139; Goldman 83 Solar Phys 89, 403). Even so, the immense effort has not produced a complete theory of several aspects of the generation of intense Langmuir waves and their conversion to radio waves.

Westerbork and the VLA have revealed that microwave, gyrosynchrotron radiation from flares usually comes from tops of magnetic loops with scales of $\sim$3" at 15 GHZ and $\sim$30" at 1.5 GHz (Kattenberg et al. 83 Solar Phys 88, 315; Marsh and Hurford 82 Ann Rev AA 20, 497; Kundu 83 Solar Phys 86, 205). Hard X rays from the same, >30 keV electron distribution usually come from footpoints (Hoyng et al. 83 ApJ 268, 865). Temporal variations in X rays and radio lasting <1 s are closely correlated, but sometimes with a small delay (Kaufman et al. 83 Solar Phys 83, 311); similarly with gamma rays which may indicate a small delay in ion acceleration relative to electron (Nakajima et al. 83 Nature 305, 292).

A new radio emission mechanism, a maser operating at a low harmonic of the cyclotron frequency, has been identified in solar and stellar flares (Holman et al. 80 IAU Symp 86; Melrose and Dulk 82 ApJ 259, 844; Gary et al. 82 ApJ 263, L79), the same mechanism which causes Earth's TKR and Jupiter's DAM. Strong arguments suggest that, in the sun and stars, maser energy is produced copiously at the fundamental cyclotron frequency but is reabsorbed by the surrounding plasma, heating it, and thus creating soft X radiation (Melrose and Dulk 84 ApJ 282, 308). If so, this is the first instance in astronomy where radio waves are energetically important.

Planets, Satellites, Comets and Asteroids - High resolution images of the Ishtar Terra region of Venus were obtained with the Arecibo 12.6 cm radar (Campbell et al. 83 Science 221, 644). The number of asteroids studied via radar techniques is increasing (Ostro et al. 83 AJ 88, 565). Radar returns from Comet IRAS-Iraki-Alcock were successfully received at both Arecibo (Campbell et al. 83 BAAS 15, 789) and Goldstone.

Ground-based observations of Jupiter's decameter radiation are still being made routinely, and are being used to attack important questions. For example, Genova et al. (81 Nature 293, 382) reported on a preliminary test of a method to study source location and structure. Dominating the low-frequency observations the last few years, however, has been the Planetary Radio Astronomy instrument on Voyagers 1 and 2. The basic results for Jupiter and Saturn were reported by Steinberg in Vol. XVIIIA, p582-584 of these Transactions. More recently a large amount of work that further organizes and interprets the data has been published. For example, there is a series of papers dealing with the Jupiter studies in 81 JGR 86, Sept. 30 issue, including an overview by Boishot et al. The Saturn observations are summarized by Warwick et al. (81 Science 212, 239 and 82 Science 215, 582). 81 Nature 292, Aug. 20-26 issue, also has a series of papers on Jupiter.

Ford et al. (83 Science 221, 1379) have mapped Venus at 17 cm using the radar receiver on Pioneer Venus. The observed features are interpreted as due primarily to emissivity variations across the surface. Work in progress includes high-resolution mapping at the VLA by Muhleman, Berge, Janssen, Klein, Chapman, and Pettengill. The four VLA wavelengths (20, 6, 2, 1.3 cm) probe to the Venus surface and to various depths in the atmosphere. 3.4 mm interferometer observations at Hat Creek by Good et al. (83 Icarus 53, 538) were used to limit the SO_2 abundance in the Venus atmosphere. Observations begun by Muhleman and Berge with the OVRO interferometer in the 2.6 mm CO(0-1) line show promise in determining the spatial distribution of CO in the upper atmosphere of Venus. Clancy et al. (83 ApJ 273, 829) determined the $^{12}CO/^{13}CO$ ratio in the Venus upper atmosphere at Kitt Peak using the CO(1-2) line.

Possible time variations of CO in the Mars atmosphere have been studied by Good et al. (81 Icarus 47, 166) and by Clancy et al. (83 Icarus 55, 282). Work is in progress by Rudy, Muhleman and Berge to interpret the observed temperature vs latitude of the Mars surface at 2 and 6 cm obtained from high-resolution VLA maps made during the retreat of the north polar cap.

The VLA has been used for high-resolution mapping of Jupiter. de Pater et al. (84 ApJ Sup 54, 405) and Roberts et al. (84 ApJ 282, 345) presented detailed maps, including polarization, of the largely nonthermal emission at 18-20 cm. These observations of synchrotron emission have the potential to help consolidate the various particle and field data for the inner magnetosphere obtained by spacecraft. Not yet published are short-wavelength VLA maps by de Pater et al. showing the Jovian atmospheric thermal emission. Valdes et al. (82 Icarus 49, 17) determined the ammonia abundance in the atmosphere of Jupiter from limb-darkening measurements made at 3.4 mm with the Hat Creek interferometer.

Saturn and the rings have been obvious subjects for VLA mapping at centimeter wavelengths. First results were published by de Pater et al. (82 Icarus 50, 88). As expected from earlier interferometry, the ring brightness was very low, and the rings caused conspicuous absorption where they crossed the disk. A limb-darkening analysis was also done. Later results can be found in de Pater et al. (83 Adv Sp Res 3, 39). Further work is in progress on other VLA maps and OVRO 3 mm interferometer data by Muhleman and Berge.

Additional analysis and interpretation of the time variation in the microwave spectrum of Uranus were presented by Gulkis et al. (83 Science 221, 453). VLA images of Uranus by Jaffe et al. (84 Science 225, 619) showing a subsolar symmetry at 2 cm and a polar symmetry at 6 cm may tie in with the wavelength dependence of the brightness temperature.

VLA measurements of Io at 2, 6, and 21 cm, consistent with thermal emission, were given by de Pater et al. (82 ApJ 261, 396). More recently, de Pater et al. (84 Icarus 57, 93) presented VLA maps of all the Galilean satellites at 2 and 6 cm showing large temperature differences between them and all lower than the IR temperatures. These are interpreted as surface emissivity effects. Similar VLA observations, as well as OVRO 2.6 mm interferometer observations, of Titan and the Galilean satellites have been made by Muhleman, Berge and Rudy. These VLA measurements of the Galilean satellites are also being analyzed for astrometric purposes by Niell et al. The 2.6 mm observations of Titan have also led to a radio detection of CO in the CO(0-1) line (Muhleman et al. 84 Science 223, 393).

Ulich, Dickel and de Pater have made new 1.3 mm planetary observations at Kitt Peak and have determined disk temperatures for Ceres as well as Callisto, Ganymede, and the major planets. Johnston et al. (82 AJ 87, 1593) observed Ceres and Pallas at 6 and 2 cm with the VLA to obtain astrometric data and flux densities.

Radio observations of comets are being vigorously pursued. For a recent review, see Snyder 82 Icarus 51, 1. The OH spectrum of comets is now rather well understood and is proving to be a useful tool to study the velocity field of the material (e.g. Bockelee-Morvan et al. 84 AA 131, 111). Attempts to detect other spectral lines or continuum emission remain frustrating because of the episodic nature of the detections, the difficulty of confirmation, and the large fraction of negative results. For example, see Gibson et al. 81 ApJ 248, 863; Crovisier et al. 81 AA 97, 195; Ekelund et al. 81 Icarus 47, 431; Snyder et al. 83 ApJ 269, L21.

GALACTIC RESEARCH

Surveys - Filled-aperture arrays ranging in size from 1 km to 600 m have been used by Ellis (82 AJP 35, 91) to obtain maps of the southern sky at frequencies of 2.1, 3.7, 4.7, 5.5, 8.3, 13 and 16.5 MHz, with angular resolution ranging from 1°.5 to 7°.5, and used to derive the emission measure as a function of galactic coordinates.

An atlas of radio continuum maps of the whole sky, made at 408 MHz with a resolution of 0°.85 has been published by Haslam et al. (82 AA Sup 47, 1). A description of the survey was previously given by Haslam et al. (81 AA 100, 209). The survey has been used to model the distribution of the galactic synchrotron emission by Phillips et al. (81 AA 98, 286; 81 AA 103, 405) and in a comparison with COS-B γ-ray data by Haslam et al. (81 Nature 289, 470). Spoelstra (84 AA 135, 238) has discussed observations of the linear polarized component of galactic radio emission at 5 frequencies between 408 MHz and 1420 MHz.

At 1420 MHz, Reich (82 AA Sup 48, 219) has surveyed the whole sky north of δ 20° with a beam of 35' arc. The maps are presented in a similar way to those of the 408 MHz survey and reach a full-beam brightness temperature of 50 mK. A survey at the same frequency and with the same resolution by Reich and Steffen (81 AA 93, 27) covers an area of 1450 sq. deg. around the southern part of loop IV ($13^h00^m < RA < 14^h40^m$, $-32° \leq \delta \leq -12°$) and achieved a similar sensitivity. Hughes (82 AA 111, 358) has mapped a 1 sq. deg. region around the Cep A condensation using the Westerbork synthesis telescope and obtained a catalogue of 20 sources stronger than 3.75 mJy: only 4 of these are thermal.

At 2.7 GHz, Graham et al. (82 AA 109, 145) have mapped a region in Monoceros of 5° x 7°, centered at l = 206°, b = -0°.5, with a beam of 4'.5 arc, in a study of the Rosette Nebula, the Monoceros nebulosity and the source G206.9 + 2.3.

Two surveys made with the RATAN-600 telescope at 3.95 GHz have been reported. Kononov and Pyatunina (83 AZh 60, 685; 83 Sov Astr 27, 4) have mapped the region of the Monoceros nebulosity ($5^h39^m \leq \alpha \leq 7^h55^m$, $-6°28' \leq \delta \leq -6°08'$) and list 93 sources having flux densities $\geq$ 20 mJy: almost twice as many as the expected number of extragalactic background sources. Pyatunina (84 Pis'ma A Zh 10, 191) surveyed three fields in the range $200° \leq l \leq 230°$ and detected 405 sources $\geq$ 30 mJy in the combined area of 0.025 sr; about 160 of these are estimated to be galactic. At sub-mm wavelengths, Stier et al. (81 Bull AAS 13, 537) have used a balloon-borne telescope to map the region $10° \leq l \leq 45°$, $|b| < 3°$ with a resolution of about 10' arc, at wavelengths of 0.15, 0.25 and 0.35 mm.

Taylor and Gregory (83 AJ 88, 1784) have made repeated surveys of the area ($40° \leq l \leq 220°$, $|b| < 2°$) at 5 GHz in a search for compact, variable sources. They list 534 discrete sources above 10-20 mJy, the completeness limit being 70 mJy. About 30 sources are variable on time scales of days to 1-2 years. One source shows periodic outbursts every 26.5 days (Coe et al. 83 MNRAS 203, 791).

Radio Stars - Radio observations of stellar systems has been a rapidly expanding field since the completion of the VLA in 1980, therefore only a small fraction of the major discoveries can be summarized. Probably the most important observations of radio stars are the VLBI observations (Lestrade et al. 84 ApJ 279, 184; Mutel et al. 84 ApJ 278, 220; Leal 84 ApJL 282, L23; Lestrade et al. 85 *Radio Stars*, eds. Hjellming and Gibson, Reidel:Dordrecht) that have established that Algol and many RS CVn binaries (HR5110, UX Ari, HR 1099) exhibit variable core-halo structures with typical brightness temperatures of (1-3) x 10^{10} K for the cores and (5-10) x 10^8 K for halos with the size scale of the binary systems.

The essential nature of radio flare stars, in doubt for many years because of questions about confusion with interference in earlier observations (Davis et al. 78 Nature 273, 644), has been well established by observations in recent years, particularly with the VLA and Arecibo. The most critical (Lang et al. 83 ApJL 272, L15) observation was a flare in AD Leo observed at 1.4 GHz at Arecibo in which a flare peaking at 120 mJy showed complex, impulsive time structure unresolved on time scales of 0.2 seconds, with almost entirely left circular polarization and brightness temperatures in excess of 10^{13} K. Weaker versions, unfortunately with poorer time resolution, have been found to be common in UV Ceti-type flare stars (Mullan 85 and Gary 85 in *Radio Stars*, eds. Hjellming and Gibson, Reidel:Dordrecht) and impulsive flaring, usually in one hand of circular polarization. A keystone to the interpretation of some of these phenomena was the VLA observations of similar radio flares from the magnetic cataclysmic variable AM Herculis (Chanmugam and Dulk 82 ApJL 255, L107) and their interpretation (Dulk et al. 83 ApJ 273, 249) in terms of optically thick gryosynchrotron emission with occasionally occurrence of cyclotron maser emission at isolated radio frequencies.

Relativistic jets produced by stellar X-ray binaries, first observed as "corkscrews" expanding at 0.26c in SS433 (Hjellming and Johnston 81 ApJL 243, L141) have also been found on two occasions following very large flares in the X-ray binary Cyg X-3, with indications of velocities of the order of 0.3c (Geldzahler et al. 83 ApJL; Johnston et al. 85 ApJ).

VLA observations of OB and WR stellar winds have measured both sizes and temperatures (Newell 81 New Mexico Tech PhD Thesis; White and Becker 83 ApJL 272, L19; Hogg 85 *Radio Stars*, eds. Hjellming and Gibson, Reidel:Dordrecht) of some winds, but simple interpretations as free-free emission from mass loss rates of 10^6 to 10^4 solar masses per year have been questioned (Underhill 84 ApJ 276, 583) with observational support from indications of time variability (Abbott et al. 84 ApJ 280, L71; Lamers et al. 85 and Rodriguez et al. 85 in *Radio Stars*, eds. Hjellming and Gibson, Reidel:Dordrecht).

Flux densities (and upper limits) at 2.3 and 8.4 GHz (S and X band) for 49 radio stars have been obtained by Estalella et al. (83 AA 124, 309). The aim is to provide a list of objects which could be observed by VLBI in order to link the positional radio reference system to the optical reference system which will be provided by Hipparcos.

Results on variability of various types of radio stars are given by Purton et al. (83 AJ 88, 1825), Geldzahler et al. (84 IAU Symp 110, 179), Hughes and McLean (84 ApJ 278, 716) and Abbot et al. (84 ApJ 280, 671). The variability of SS433 has been studied by Seaquist et al. (82 ApJ 260, 220), Bonsignori-Facondi (83, Workshop on "Astrophysical Jets", Reidel p. 161) and Johnston et al. (84 AJ 89, 509). Radio emission from the Nova SU UMa has been observed with the Bonn 100 m telescope (Benz et al. 83 Nature 302, 45).

Pulsars - The discovery of a 1.6 ms pulsar, PSR1937+21, at Arecibo (Backer 82 Nature 300, 615) has rejuvenated research into the final states of isolated and binary stars (Ruderman 83 Comments Ap 10, 15; van den Heuvel 84 JAA 5, 209). Boriakoff announced the discovery of a 6.1 ms pulsar in a 123-day binary (83 Nature 304, 417). Many observational and theoretical developments spawned by these discoveries were reviewed at a Green Bank Workshop in June 84 (proceedings referenced below as GBWS, eds. Reynolds and Stinebring). Millisecond pulsar observations are reviewed by Backer (84 JAA 5, 187).

The sharp pulse of PSR1937+21 and its low rotation noise suggest that ms pulsars may provide a clock for long time scales (Backer 83 Nature 301, 314; Ashworth 83 Nature 301, 313). An accurate pulsar time scale can lead to improved values for the orbit of the Earth and to detection of gravitational waves (Romani 82 ApJ 265, L35; Hellings 82 ApJ 265, L39; Bertotti 83 MNRAS 203, 945; Hogan 84 Nature). Limits to timing accuracy have been analyzed by Blandford (84 JAA Dec). Acquisition of pulsar arrival time data at Arecibo with <100 ns IAT error has required improvements in software, hardware and time transfer (Davis 84 GBWS). Timing measurements also continue at Jodrell Bank.

Binary PSR1913+16 observations continue to confirm the orbit decay predicted by general relativity (Weisberg 84 Phys Rev Let 52, 1348; Boriakoff 82 ApJ 261, L97). The Vela pulsar glitched again (McCulloch 83 Nature 302, 319). The braking index of PSR1509-58, a young X-ray/radio pulsar, is n=2.83 (Manchester 84 GBWS). A $P/\dot{P}$ study by Cowling (83 MNRAS 204, 1237) places a new limit on the existence of a solar companion. New timing program results: Downs (83 ApJSS 53, 169); Manchester (83 MNRAS 202, 209) and Gullahorn (82 ApJ 260, 520). Crab timing continues at Jodrell.

Gwinn (84 Princeton PhD) has determined parallaxes for PSR0950+08 (7.9±0.8 mas) and PSR0823+26 (1.8±0.4 mas) with VLBI. Fomalont's (84 MNRAS 210, 113) comparison of timing and interferometer positions shows unexplained systematic $0''.3$ discrepancies between the two reference frames. Lyne (82 MNRAS 201, 503) has measured proper motions which imply a curious correlation with inferred surface field (Anderson 83 Nature 303, 597) and allow a comparison with scintillation parameter velocities (Lyne 82 Nature 298, 825; Cordes 84 GBWS).

The search for counterparts of radio pulsars at X and gamma rays (Thompson 83 AA 127, 220; Buccheri 83 AA 128, 245; Graser 83 ApJ 272, 681; Knight 82 ApJ 260, 553) and at optical wavelengths (Lebedev 83 AZh 60, 742) have been successful. The ms pulsars have not been detected (Loredo 84 GBWS; Manchester 84 Nature 310, 569). Xray synchrotron nebulae have been detected for 1055-51 (Cheng 83 ApJ 3=271, 271) and 1509-58 (Seward 84 ApJ 281, 650). Observations of the Crab at high energy continue (Knight 82 ApJ 260, 538; Wilson 83 ApJ 269, 273; Beskin 83 PAZh 9, 280).

Rankin (83 ApJ 274, 359; 274, 333) presented an observational synthesis of pulsar beaming. Narayan (82 AA 113, L3; 83 AA 122, 45) presented a strong case for elongated beams in the unseen coordinate. Others have investigated evolution of beaming (Wu 82 AASin 23, 140; Kuz'min PAZh 9, 149). Stinebring (84 ApJSS) published new polarization data. Pulse nulling and mode changing were studied with emphasis on PSR0809+74 (Fillipenko 82 ApJ 263, 828; Lyne 83 MNRAS 204, 519; Popov 82 AZh 59, 719; Bartel 82 ApJ 258, 776; Davies 84 MNRAS). While Perry at Jodrell Bank reports detection of continuous point-source emission for several pulsars, Kesteven (82 AA 113, 211) and Cohen (83 ApJ 264, 173) do not detect extended emission near pulsars. Important studies of polarization at 39 MHz have been reported by Sulejmanova (83 AZh 60, 554).

The discovery of millisecond pulsars has led to new surveys for fast pulsars employing new techniques. Most are summarized in GBWS: polarized point source (Jodrell, Berkeley/WSRT); interstellar scintillation (Berkeley/GB); scintar/pulsars (many); offline analysis of data (Parkes, Jodrell, Princeton/GB, Princeton/NAIC); online search with pipeline multiprocessor (Berkeley).

Pulsars in the LMC have been found at radio wavelengths (McCulloch 83 Nature 303, 307) and at X-rays; the latter is surrounded by a synchrotron nebula.

Interstellar propagation studies focused on three areas: galactic distribution of turbulence; refractive effects (Seiber 82 AA 113, 311; Roberts 82 MNRAS 201, 1119; Rickett 84 AA; and "applications" to pulsar studies (Lyne 84 Nature 310, 300; Cordes 83 ApJ 268, 370).

The maximum rotation speed of pulsars is discussed by Freidman (83 Phys Rev Let 51, 11). Binary evolution scenarios and neutron star production scenarios are reviewed by van den Heuvel (84 JAA 5, 209) and Chevalier (84 GBWS), resp. Vital to these discussions is a provocative discussion on production of strong magnetic fields by cooling neutron stars (Blandford 83 MNRAS 204, 1025). The relation of pulsars and supernovae remains a puzzle (Radhakrishnan 82 Contemp Phys 23, 207). Lyne (84 MNRAS) has summarized current understanding of galactic distribution of pulsars. X-ray observations of synchrotron nebulae or the neutron star itself are important (Becker 82 ApJ 255, 557).

Supernovae and Supernova Remnants - Supernova (SN) and supernova remnant (SNR) research has grown substantially during the last triennium. This is partly due to the quantum jump in resolution and sensitivity provided by the VLA and partly the result of cross-fertilization from other areas, especially X-ray astronomy, as demonstrated by the large amount of radio data presented at the 1983 IAU Symposium 101 on SNR and their X-ray emission. Progress in the study of SN has been particularly striking with a doubling of the total number detected at radio wavelengths, including the first SN discovered by other than optical techniques. SNR research has been highlighted by radio surveys of several external galaxies with sufficient resolution to reveal the structure of many of the remnants studied, improved maps of many SNR in our Galaxy, and new ideas on their statistics.

Bignell and Seaquist (83 ApJ 270, 140) have studied the luminous SN in NGC 4449 and confirmed variability at 5 GHz. With the detection of radio emission from SN1980k in NGC 6946 (Weiler et al. 83 IAU Symp 101, 171) and the radio discovery of a SN in NGC 4258 (Van der Hulst et al. 83 Nature 306, 566; 83 PASP 95, 607), the number of radio supernovae has increased to four. Three are of Type II (there is insufficient information to classify the SN in NGC 4258) and their characteristics are rather divergent. Nevertheless it is clear that models involving the sudden injection of relativistic particles which subsequently cool adiabatically are inconsistent with the data. Rather, a pulsar-powered source initially shielded by a dense shell of material (Salvati, 83 IAU Symp 101, 177) or particle acceleration by the blast wave plowing through a cocoon of circumstellar matter (Chevalier, 81 ApJ 251, 259) have been suggested. An unsuccessful search for radio emission from recent SN in nearby galaxies was made by Cowan and Branch (83 ApJ 258, 31).

Observations of external galaxies are now contributing significantly to radio studies of SNR. Mills et al., selecting objects on the basis of X-ray data, present maps of SNR in the Small (82 MNRAS 200, 1007) and Large Magellanic Clouds (84 AJP 37, 321)--38 sources in all. Mathewson et al. (83 ApJ Sup 51, 345) also used optical data in studying a similar number of LMC and SMC remnants. More distant galaxies have turned up fewer detections: a handful each in M31 (82 ApJ 252, 582; 84 MNRAS 206, 351) and M33 (82 MNRAS 198, 1059; see also 83 AA 120, 147). In addition, there have been observations of singular SNR candidates in other galaxies, especially NGC 4449 (83 AA 119, 301; 83 ApJ 270, 140) and M82 (83 IAU Symp 101, 583). Statistical studies based on SNR in the LMC, SMC, M31 and M33 and presented in papers cited above suggest that the onset of the adiabatic phase occurs quite late in remnant evolution. This conclusion has been disputed by Green (84 MNRAS 209, 449) who, in presenting and discussing a new inventory of galactic SNR, suggests existing catalogues are quite incomplete. Several authors have commented on the large scatter in the surface brightness-diameter relationship and on its unreliability for determining distances (83 IAU Symp 101).

Morphological studies of galactic SNR have substantially increased the number of high quality maps available of both northern (81 AJ 86, 1003; 81 AA 103, 277; 81 AA 103, 393; 81 J. Astrophys. Astron. 2, 339; 82 AA 105, 176; 82 AA 109, 145; 82 ApJ 261, L41; 82 AJ 87, 1379; 82 J. Astrophys. Astron. 3, 207; 83 MNRAS 203, 695; 83 AJ 88, 1810; 83 Pub.A.S.Jap. 35, 437; 83 Pub.A.S.Jap. 35, 447; 84 AA 131, 196; 84 AA 133, 11) and southern (82 AA 106, 314; 82 MNRAS 200, 1143; 82 MNRAS 203, 595; 83 MNRAS 204, 237; 83 MNRAS 204, 833; 83 MNRAS 204, 915; 83 MNRAS 204, 921; 83 ApJ 271, L55) remnants. There has also been work which combined radio and X-ray data (81 ApJ 248, L23; 83 ApJ 266, 684; 83 ApJ 268, L93; 84 MNRAS 207, 649) and from a consideration of radio morphologies (Shaver (82 AA 105, 306) concludes that shell SNR are brightest on the side nearest the galactic plane. HI studies have been made both for determining SNR distances (82 Reg. of Rec. Star Form. 193; 82 SovA 26, N1; 82 Nature 299, 606) and investigating nearby gas (81 SovA 25, 675; 82 AA 112, 141; 83 A&AS 53, 57; 84 AA 130, 295). There have also been molecular cloud studies of SNR which often show associations (81 Nature 293, 549; 83 AJ 88, 297). The decrease in flux density of several young SNR has been monitored by Ivanov et al. (82 Sov AJ Let 8, 42), while the expansion of Tycho was determined by Strom et al. (82 MNRAS 200, 473) and that of Cas A by Tuffs (83 IAU Symp 101, 49).

SNR resembling the Crab have not been neglected, as shown by the special issue of Observatory (83 Obs 103, 73-116; see especially reviews by Wilson and Weiler). In a search for such remnants, Helfand et al. (84 AJ 89, 819) conclude that few are missing from existing catalogues. Related objects appear in an SS433 conference (81 Vistas 25) and Velusamy and Kundu mapped the center of CTB80 (83 J. Astrophys. Astron. 4, 253).

The Galactic Center - The major new observational results include a series of high-resolution VLA radio images of sources within the central square degree of the Galaxy. The radio source at the center, Sgr A, was shown (Ekers et al 83 AA 122, 143) to consist of (i) a ∿10-pc oval shell of nonthermal emission, Sgr A East, and (ii) a ∿3-pc spiral-like distribution of thermal emission, Sgr A West, (Lo et al. 83 Nature 306, 647; Brown et al 83 ApJ 268, L85). On a larger scale, the "arc-feature" at $\ell = 0\overset{\circ}{.}18$ has been resolved into several long (∿50 pc), linear "strands" of emission with curved features merging with the diffuse halo of Sgr A (Yusef-Zaheh et al. 84 Nature 310, 557). These linear features are at the base of a giant Ω-shaped radio loop, straddling the galactic center and extending above the galactic plane by more than 1° (∿200 pc) (Sofue et al. 84 Nature 310, 568). The compact nonthermal radio source at the centroid of Sgr A West was shown to have an elongated structure at 3.6 cm (Lo 84 IAU Symposium 110, 265). HI, CO and HNC observations (Liszt et al. 83 AA 126, 341; Fukui et al. 83 ApJ

275, L55) indicated the existence of neutral gas within 5 pc of the center, perhaps providing the material falling in towards the center--a possible explanation of the ionized gas in Sgr A West (Lo et al. 83; Ekers et al. 83).

HI - Increasing sensitivity, bandwidth coverage and spectral resolution have continued to improve the 21 cm line systems on major single dish telescopes. The preliminary reports of new surveys of the southern hemisphere promise many exciting results, especially in the regions of the Magellanic Clouds and the Magellanic Stream. Much of the detailed 21 cm work on the Milky Way is designed to correlate the HI clouds with other constituents of the interstellar medium. In the region of the South Celestial Pole, King et al. (82 MNRAS 198, 255) find a correlation between gas and dust by examining the HI and optical emission. HI is also seen in association with supernova remnants (Stacy and Jackson 82 Nature 296, 42; Sofue 83 Pub.A.S.Jap. 35, 91; Lockman and Genzel 83 ApJ 268, 117) surrounding CO clouds (Wannier et al. 83 ApJ 268, 727), and in self-absorption towards an OB association (Bania 81 AJ 88, 1222). Absorption spectra have been measured by Dickey et al. (83 ApJ Sup 53, 591) with the VLA and Mebold et al. (82 AA 115, 223) with the Bonn and Green Bank dishes.

Heiles and Troland (82 ApJ 252, 179) have measured the Zeeman splitting in the vicinity of Orion and in expanding HI shells; in eight HI emission regions, the weakness of the magnetic field precludes the alignment of dust grains by the conventional mechanism. Bregman et al. (82 AA 118, 157) have detected Zeeman splitting in absorption toward Cas A.

Detailed studies of the structure and distribution of high velocity HI clouds (Schwarz and Oort 83 AA 101, 305; Mirabel 82 ApJ 256, 112), especially the Magellanic Stream (Cohen 82 MNRAS 199, 291; Morras 83 AJ 88, 62), suggest that most of the phenomena result from the recent tidal interaction of the Milky Way and the Magellanic Clouds (Giovanelli 81 AJ 86, 1468).

HII Regions and Recombination Lines - New surveys of galactic HII regions were made by Wink et al. (82 AA 108, 227) in the radio continuum and recombination line (RRL), and Blitz et al. (82 ApJ Sup 49, 183) in the CO line. At least 70% of all HII regions have associated molecular clouds. Fich and Blitz (84 ApJ 279, 125) have studied the distribution and properties of HII regions in the outer galaxy. Distances have been determined for a few HII regions using H_2O maser proper motions (e.g. Schneps et al. 81 ApJ 249, 124). Much effort has gone into continuum and line mapping of individual HII regions. VLA observations reveal shell structure in compact HII regions (e.g. Turner and Matthews 84 ApJ 277, 164), and detect ultracompact HII regions embedded in more diffuse nebulae and molecular clouds (e.g. Moran et al. 83 ApJ 271, L31); turnover frequencies are as high as 20-30 GHz, and electron densities $\sim 10^7$ cm^{-3}. Garay et al. (84 ApJ, in press) find that main-line OH masers are invariably associated with such ultracompact HII regions.

Magnetic fields within HII regions have been studied using Faraday rotation of the polarized radiation from background sources (Heiles et al. 81 ApJ 247, L77), and the Zeeman effect in RRLs (Silvergate 84 ApJ 279, 694). The cosmologically important 8.7 GHz hyperfine line of $^3He^+$ was detected in a few HII regions (Rood et al. 84 ApJ 280, 629). RRLs were used to determine ^4He abundances and electron temperatures (e.g. McGee and Newton 81 MNRAS 196, 889; Lockman and Brown 82 ApJ 259, 595; Garay and Rodriguez 83 ApJ 266, 263; Wink et al. 83 AA 127, 211), and the galactic abundance gradient (Shaver et al. 83 MNRAS 204, 53).

Low frequency (20-30 MHz) carbon RRLs have been detected in the spectrum of Cas A (Konovalenko and Sodin 80 Nature 283, 360; 81 Nature 294, 135); these are the lowest-frequency spectral lines, and the first RRLs to be observed in absorption. Low-frequency RRLs have also been used to study the properties of the low-density outer parts of HII regions (Anantharamaiah, 84 PhD Bangalore), and the diffuse interstellar medium (Ariskin et al. 82 Sov AJ 26, 23; Payne et al. 84 AJ 89, 668).

Interstellar Molecules - The scientific developments in molecular line radio astronomy are moving away from the discovery phase and toward a consolidation and deepening of our knowledge. Over the next few years, great advances will be made in producing high spatial resolution maps in centimeter lines with the VLA, and in millimeter lines with the Berkeley, Caltech, IRAM and Nobeyama interferometers. The 45-m Nobeyama and 30-m IRAM single dishes, when combined with state-of-the-art receivers, should allow an order of magnitude improvement in sensitivity. The soon-to-be-released IRAS data will provide a starting point for many comparisons of IR properties with molecular cloud parameters. Searches for specific molecules, such as the biologically important species Glycine (Snyder et al. 83 ApJ 268, 123), the reported detection of the long chain carbon $HC_{11}N$ (Bell et al. 82 Nature 295, 389), the detections of CH_3C_3N (Broten et al. 84 ApJ 276, L25) and CH_3C_4H (Walmsley et al. 84 AA 134, L11; MacLeod et al. 84 ApJ 282, L89) have taken place. The assignments of lines to exotic, "non-terrestrial" species have been made by Thaddeus et al. (81 ApJ 246, L41). Searches for HOC^+ (Woods et al. 83 ApJ 270, 583) have been made, and the assignment of a number of unidentified lines to the first ring molecule, SiC_2, in the shell of the carbon star IRC+10216 (see e.g. Olofsson et al. 82 AA 107, 128; Knapp et al. 82 ApJ 252, 616) have been made by Thaddeus et al. (84 ApJ 283, L45). All of this work depends on the availability of laboratory measurements or accurate molecular structure models. Frequency scans give an estimate of the number and intensity of spectral lines in a given range. The best and most complete data are in a 3 mm frequency scan of Orion-KL carried out at the Onsala Space Observatory (Johansson et al. 84 AA 130, 22). These results showed only a few unidentified lines. At higher frequencies, the 200-265 GHz frequency scan of Orion-KL done by the Caltech group shows a similar result.

A great deal of effort has gone into the study of molecular outflows from low mass stars, which in some cases are bipolar (see Snell and Edwards 83 ApJ 279, 668; Bally and Lada 83 ApJ 265, 824). The mechanism for the production of large momentum fluxes deduced from CO outflows is unknown. Lower resolution maps (Bastien et al. 81 AA 98, L4, for Orion-KL; Torrelles et al. 83 ApJ 274, 214, for lower velocity outflows) seemed to indicate that the outflows were focussed by quiescent molecular clouds. However, on scales of 30" this does not seem to be the case (Takano et al. 84 ApJ 282, L69). On a smaller scale, this possibility has been applied to the Orion-KL outflow by Plambeck et al. (82 ApJ 259, 617). There are a rather large number of hot molecular clouds in the galaxy. For the Orion-KL and Sgr B2 clouds, the kinetic temperatures have been estimated by observations of many transitions of CO (Storey et al. 81 ApJ 247, 136; Stacey et al. 82 ApJ 257, L37; Koepf et al. 82 ApJ 260, 584), vibrationally excited HC_3N (Goldsmith et al. 82 ApJ 260, 147), SO_2 (Schloerb et al. 83 ApJ 264, 161); torsionally excited methanol (Lovas et al. 82 ApJ 253, 149) and NH_3 at 1.3 cm (Wilson et al. 82 AA 115, 185). For the Orion region near the KL nebula the kinetic temperature estimates range from $\sim$ 80 K to 10^3 K. However, the centers of the molecular emission are spatially separated. The high velocity wings in J = 3-2 line of CO (Erickson et al. 82 ApJ 261, L103) are $\sim$10" north of the centers of the hot Ammonia peaks seen with the VLA (Genzel et al. 82 ApJ 259, L103; Pauls et al. 83 AA 124, 23).

High quality single-dish maps may allow accurate determinations of the spatial distributions of many species (Olofsson et al. 82 AA 113, L18; Batrla et al. 83 AA 128, 279; Hasegawa et al. 84 ApJ 283, 117). For maps in a single line, however, the trend is toward interferometry (see Forster et al. 81 MNRAS 197, 513; Welch et al. 81 ApJ 245, L87; Harris et al. 83 ApJ 265, L63; Johnston et al. 83 ApJ 271, L89). Although the spatial distributions of the line intensities of various molecules are different, it is not completely clear that the distributions of these molecules differ. High angular resolution maps of warm clouds are also necessary if comparisons are to be made between the location of IR sources or stars and molecular clouds, similar to those made for nearby cold clouds by Myers and Benson (83 ApJ 266, 309). In addition to the VLA results for Orion-KL, VLA observations of NH_3 emission in W51 (Ho et al. 83 ApJ 266, 596) show large kinetic temperatures (from the line brightness temperatures) directly. For the hot clouds in the galactic center (Güsten et al. 81 AA 103, 197), the source of heating is not certain. Emission line measurements toward Orion-KL (Genzel et al. 82 ApJ 259, L103; Pauls et al. 83 AA 124, 23), and absorption line data taken toward the compact HII regions in W31 and NGC 7538 (T.L. Wilson et al. 83 AA 127, L19) show that these hot molecular clouds also appear to have large concentrations of Ammonia. Multi-line analyses also have been used to determine H_2 densities and scale sizes in molecular clouds (Vanden Bout et al. 83 ApJ 271, 161; Schloerb et al. 83 ApJ 267, 163); Plambeck et al. 82 ApJ 266, 321; Ho et al. 81 ApJ 246, 761; Batrla et al. 82 AA 119, 139; Mauersberger et al. 83 Mitt. A.G. 60, 402; Martin-Pintado et al. 83 AA 117, 145; Martin et al. 84 MNRAS 208, 35). The optical depth in many such lines is significant, and the trend is to use a multi-line analysis of rarer isotopic species (Henkel et al. 83 AA 127, 388); in the future, a comparison of different lines of the same species, mapped interferometrically, will become more common (Genzel et al. 82 ApJ 259, L103.

Isotope studies showed that the $^{12}C/^{13}C$) ratios obtained from H_2CO (Henkel et al. 82 AA 109, 344) and $^{13}C^{18}O$ (see R.W. Wilson et al. 81, ApJ 243, L47) give a ratio which is close to terrestrial, for sources near the Sun. Studies of the polarization of absorption lines of molecules such as OH (Crutcher et al. 81 ApJ 249, 134) will lead to better estimates of the magnetic fields, via the Zeeman effect, in what are certainly the denser portions of molecular clouds. In SiO, polarization has also been found (e.g. Clark et al. 82 ApJ 261, 569). This is not caused by the Zeeman effect. Theoretical studies (Goldreich and Kylafis 82 ApJ 253, 606) have shown that, in the general interstellar medium, polarization in the radiation from molecules other than OH might be detectable, and searches for this effect are underway. Frerking et al. (82 ApJ 262, 590) have related the column density of $^{13}C^{16}O$ and $^{12}C^{18}O$ to the visual extinction, A_v, for nearby dust clouds in Taurus and Ophiucus. The extinction was related to the column density of H_2 using the standard gas-to-extinction ratio. Attempts to determine a spiral pattern in our galaxy from CO data can now begin, since a combined north-south data set (taken with different telescopes) has been presented by Robinson et al. (84 ApJ 283, L31). A more uniform data set, from work of the Goddard group, is expected soon. However, the results may be strongly affected by non-circular velocity streaming motions.

Interstellar Masers - Observations and theoretical advances in the study of molecular masers prior to this report have been summarized by Reid and Moran (81 Ann Rev AA 19, 231).

A new application of the technique of statistical parallax has been used to measure distances to H_2O masers in W51 by Genzel et al. (81 ApJ 247, 1039) and Schneps et al. (81 ApJ 249, 124). These studies extend direct astronomical distance measurements by more than an order of magnitude. Walker et al. (82 ApJ 255, 128) used new VLBI fringe-rate analysis techniques and mapped 386 maser components in W49; results based upon these observations indicate for the first time hyperfine splitting in H_2O maser emission.

Abraham et al. (81 AA 100, L10) monitored the dramatic variations in the great Orion H_2O maser flare which exceeded 10^6 Jy while Matveyenko et al. (83 Sov AJ Let 9, 240) have measured the angular size of the flaring region with the Simeiz-Pushchéno interferometer. New H_2O masers associated with far IR sources were discovered by Jaffee et al. (81 ApJ 250, 621) and other new sources were reported by Dickinson and Dinger (82 ApJ 254, 136), Haschick et al. (83 ApJ 265, 281), Scalise et al. (81 AA 104, 166), Gusten and Downes (83 AA 117, 343), Braz and Scalise (82 AA 107, 272), Sandell and Olofsson (81 AA 99, 80) and others.

Accurate positions for 6 cm excited OH masers were determined by Rickard et al. (82 AJ 87, 1806). VLBI synthesis maps of the OH maser emission in NGC 7538 were completed by Forster et al. (82 MNRAS 201, 7P). Benson et al. (82 ApJ 253, 199) and Kent and Mutel (82 ApJ 263, 145) reported main-line OH VLBI results. VLA observations of OH masers associated with compact HII regions have been reported by Ho et al. (83 ApJ 265, 295) and Garay (83 PhD Thesis, Harvard U.). Maps of OH emission from IR stars (e.g., Norris et al. 82 Nature 299, 131; Diamond et al. 84 MNRAS 207, 611) and from Orion (Norris et al. 84 MNRAS 207, 127) were made with the MERLIN telescope. VLA observations of stellar OH sources were published by Baud et al. (81 ApJL 250, L79), Reid et al. (81 AJ 86, 897), and Bowers et al. (83 ApJ 274, 733). An unusual OH source was reported by Morris and Kazes (82 AA 111, 239). The evolution of the peculiar OH star U Ori was monitored by Jewell et al. (81 ApJ 249, 118). The luminosity function and spatial distribution of OH masers in the Galaxy has been studied by Tors et al. (84 Acta Ap Sinica 4, 96).

Polarization properties of SiO masers have been observed (Clark et al. 84 ApJ 276, 572) and simultaneous observations of several transitions have been made (Schwartz et al. 82 ApJL 256, L55). Relative positions of the two SiO maser peaks in Orion were reported by Lane (82 PhD Thesis, U. Mass.) and by Wright et al. (83 ApJL 267, L115). Isotopic maser emission may have been detected in ^{29}SiO by Olofsson et al. (81 AA 100, L30) and Deguchi and Rieu (83 AA 117, 314) from the Orion source. Sun et al. (84 Acta Ap Sinica 4, 104) have modeled the velocity spectra of Mira Variable SiO masers by stellar pulsations. Potential new masing molecular species and transitions were discovered: SiS (Henkel et al. 83 ApJ 267, 184) and SiO J=5-4 (Clemens et al. 83 ApJL 266, L117).

EXTRAGALACTIC RESEARCH

Surveys of Extragalactic Sources - Two new 5C surveys have been completed. The 5C10 survey (Schuch 81 MN 196, 695 and 83 MN 204, 1245) covers the Ursa Major supercluster and lists 265 sources $\geq$ 9.8 mJy and 48 sources $\geq$ 1.7 mJy at 408 and 1407 MHz, respectively. The source counts for this special field appear consistent with those from other 5C surveys. The 5C12 survey (Benn et al. 82 MN 200, 747) covers a region near the north Galactic pole and lists 299 sources $\geq$ 9 mJy and 65 sources $\geq$ 1.4 mJy at 408 and 1407 MHz, respectively. Magnitudes and colors for 1200 objects near the 5C12 sources are given in a separate paper (Grueff et al. 84 MN 206, 475).

At 1.45 GHz, Condon and Mitchell (82 AJ 87, 1429 and 84 AJ 89, 610) have surveyed a region centered at RA = 08 52 15, δ = 17°16'. They find 159 sources $\geq$84 μJy, of which 45 are identified with objects brighter than B = 21.5. They have used the P(D) technique to extend the number-flux relation to 30 μJy.

The RATAN-600 telescope has been used to make two surveys. The first, made at 8.7 and 14.4 GHz (Amirkhanyan et al. 81 AZh 58, 717; Sov Astr 25, 412) covers the region 0° $\leq \delta \leq$ 4° and lists 82 sources $\geq$ 0.36 Jy and 24 sources $\geq$ 0.79 Jy at the respective frequencies. The surveys are believed to be 98 percent complete at 0.45 and 1.01 Jy, respectively. The second, made at 3.95 GHz, covers the region $4°44' \leq \delta \leq 4°54'$ and is 75 percent complete above 0.8 mJy (Berlin et al. 81 Sov AJ Let 7, 161). Source counts down to 0.86 Jy have been derived from the section $13^h \leq RA \leq 14^h$ and down to 7.5 mJy from the rest of the region. The counts converge down to 0.86 mJy, where the source density reaches 2×10^5 sr^{-1}.

Near 5 GHz, previous survey work has been extended with single dish surveys by Wall et al. (82 MN 200, 1123) of a 27 sq. deg. region at RA = 22^h, $\delta = -18°$ down to 32 mJy. Owen et al. (83 AJ 88, 1) list 480 sources $\geq$ 35 mJy in a 0.0691 sr area with $07^h04^m \leq RA \leq 17^h56^m$, $34°09' \leq \delta \leq 35°51'$. In both cases, the surveys have been followed by optical identification work, by Savage et al. (82 MN 200, 1135) and Condon and Ledden (82 AJ 87, 219); in both cases only a small fraction of the fainter sources can be identified with flat-spectrum QSOs. Wall et al. (82 MN 198, 221) have extended the number-flux relation down to ∿ 1 mJy using the P(D) technique and find the convergence suggested by the direct source counts continues. A dramatic step to even lower flux density levels has resulted from VLA surveys at 1.4 and 4.9 GHz.

Little survey work has been done at frequencies above 5 GHz. Seielstad has surveyed five 1 sq. deg. fields at 10.6 GHz down to 50 mJy, but detected only 2 sources (83 PASP 95, No. 563, 32). Seielstad et al. (81 ApJ 244, 717) have used the P(D) technique on 10.6 GHz data to put limits of (0.25 to 3.3) x 10^6 sr^{-1} Jy^{-1} on the source density near 10 mJy. The limited 14.4 GHz survey by Amirkhanyan et al. has been referred to earlier.

Further progress in the definition of the high-frequency source counts can be expected from additional VLA surveys. The application of the P(D) method to VLA data has already extended the counts to ∿ 10 μJy, but the direct counts below 1 mJy are still based on only a small number of sources. With improvements in receivers and multi-beaming techniques, extensive surveys near 15 GHz should become feasible soon.

Cosmological Tests - The period under review has seen a remarkable extension of source counts near 21 and 6 cm λ to the sub -mJy level. At 21 cm, Westerbork surveys down to ∿ 0.6 mJy (van der Laan and Windhorst 82 Astrophysical Cosmology, p349) suggested a possible upturn in the normalized differential counts below a few mJy. Subsequent deeper surveys with the VLA (Windhorst et al. 84 AA Sup 58, 1; Condon and Mitchell 82 AJ 87, 1429) going down to 85 μJy for individual sources and to ∿ 30 μJy by a P(D) analysis (Condon and Mitchell 84 AJ 89, 610) have confirmed a significant flattening of the counts below ∿ 5 mJy. Deep photometry shows a faint blue galaxy population dominating at low flux levels that could be responsible for the upturn (van der Laan et al. 83 IAU Symp 104, 73; Windhorst 84).

Sub-mJy counts near 5 GHz based on VLA surveys have been reported by Bennet et al. (83 Nature 301, 686) and Fomalont et al. (84 Science 225, 23), the latter survey reaching ∿ 60 μJy by direct counting and ∿ 10 μJy by a P(D) analysis. The 6 cm counts show rapid convergence below ∿ 100 mJy and also show the flattening at very low flux levels seen near 20 cm. The convergence in the counts down to ∿ 1 mJy was also inferred from a P(D) observation with the Effelsberg dish by Wall et al. (82 MNRAS 198, 221) who also point out that an earlier discrepant P(D) result with the Parkes dish (Wall 78 MNRAS 182, 381) could be attributed to an instrumental error. Counting "flat" and "steep" spectrum sources separately at 5 GHz shows (Wall and Benn 82 IAU Symp 97, 441; Fomalont et al. 84) that while the former begin to converge below ∿ 1 Jy, the latter do so only below ∿ 100 mJy. This gives the total counts a near "Euclidean" slope over a wide range in flux density. The similar shapes of the subcounts imply evolution for both types of sources, a result that is now supported by the V/V_m tests and also by the multifrequency "free-form" models of the evolution of the Radio Luminosity Function (Peacock and Gull 81 MNRAS 196, 611).

Swarup et al. (82 AA 107, 190; Astrophysical Cosmology, p383) have used the statistics of optical identifications with galaxies to constrain evolutionary models. A multifrequency model using a "parametric" evolution function has also been proposed (Subrahmanya and Kapahi 83 IAU Symp 104, 47). Cavaliere et al. (82 AA 114, L1; 83 ApJ 269, 57) report a physical model for the evolution of luminosity functions based on the conversion of gravitational energy in supermassive black holes.

The suggestion by Hawkins and Steward (81 ApJ 251, 1) that the V/V_m statistics of quasars could be compatible with "no evolution" in view of the selection effect against recognizing quasars at low redshifts has been shown by Avni and Schiller (83 ApJ 261, 1) and by Wills (83 ApJ 270, 48) to have little effect on the conventional interpretation of V/V_m tests.

The possibility of detecting a dipole anisotropy in radio source counts similar to that in the microwave background radiation, in order to test the isotropy of the Universe has been discussed by Ellis and Baldwin (84 MNRAS 206, 377).

The angular size - redshift relation for radio quasars and its interpretation has been investigated by several authors (Ulvestad et al. 81 AJ 86, 1010; Nottale 82 AA 113, 223; Okoye and Onuora 82 ApJ 260, 37; Onuora and Okoye 83 ApJ 270, 360; Hintzen et al. 83 AJ 88, 709; Swarup et al. MNRAS 208, 813) but no definite conclusions with regard to the possible evolution of linear size with epoch has been possible mainly because of the correlation between redshift and luminosity in the existing data.

New determinations of angular sizes down to $\sim$ mJy level at 408 MHz have confirmed that the median angular size (θ_m) of radio sources appears to saturate at $\sim$ 10 arcsec (Kapahi and Subrahmanya 82 IAU Symp 97, 401; Downes 82 IAU Symp 97, 393; Downes et al. 81 MNRAS 197, 593; Fielden et al. 83 MNRAS 204, 289). Westerbork surveys at 21 cm in fact show that θ_m remains at this level even down to $\sim$ 1 mJy (Windhorst 84). The interpretation of the θ_m-S relation is however still controversial because the predicted relation depends on the unknown redshift of weak radio sources.

New limits to small scale fluctuations in the CBR have been published by Fomalont et al. (84 ApJL 277, L23); Uson and Wilkinson (84 ApJL 277, 1); Lasenby and Davies (83 MNRAS 203, 127; and Berlin et al. (82 IAU Symp 104, 121). On larger scales, measurements of the dipole anisotropy have been refined, but no quadrupole moment has been detected (Lubin et al. 83 Phys Rev Let 50, 616; Fixen et al. 83 Phys Rev Let 50, 620). Improved low frequency measurements of the CBR spectrum give a value of 2.79±0.10 K with no evidence of departure from a black body curve over the range 2.5 to 90 GHz.

Flux Densities and Spectra - Flux density measurements of extragalactic sources have been reported over a wide range of frequencies. Over two hundred sources from the 1 Jy catalogue of Kuhr et al. have been measured at 408 MHz with the Bologna Cross by Gregorini et al. (84 AJ 89, 323). Radio sources from the Parkes 2.7 GHz survey have been measured at 5 GHz (Binette et al. 81 AJP 34, 445) and at 8.87 GHz (Shimmins et al. 81 AJP 34, 471). Lawrence et al. (83 ApJ Sup 51, 67) reported 5 GHz flux densities of 2911 sources in the Arecibo 611 MHz survey. Radio sources selected from the NRAO-MPI 5 GHz surveys have been measured at 31.4 GHz by Geldzahler and Witzel (81 AJ 86, 1306) and Geldzahler and Kuhr (83 AJ 88, 1126). Abraham et al. (84 AJ 89, 200) measured flux densities at 22 GHz and at

44 GHz for 30 and 16 sources respectively. Millimeter observations data of several radio sources are given by Ennis et al. (82 ApJ 262, 460) and Gear et al. (84 ApJ 280, 102).

5 GHz flux densities and discussions on the radio spectra of complete samples of radio sources are presented by Machalski and Maslowski (82 AJ 87, 1132) for the GB/GB2 survey and by Slee et al. (82 PASA 4, 278) for the Culgoora survey. Efenov et al. (83 Izv. Krymskoy Astrofiz. Obs., 66, 205) discuss the radio spectra of 143 extragalactic radio sources in a frequency range up to 22 GHz.

Gopal Krishna and Steppe (81 AA 118, 150) and Steppe and Gopal Krishna (84 AA 135, 39) investigated the dependence of median (decimeter-wavelength) spectral index on the 408 MHz flux density and find a significant correlation. Owen et al. (83 AJ 88, 1) made a similar analysis for source samples selected at 5 GHz and confirmed a monotonic decrease in the fraction of flat spectrum sources fainter than 100 mJy.

Variability - Wardle et al. (81 AJ 86, 848) give results on variability of a sample of extragalactic sources at 2.7 GHz. They find evidence for variability as fast as 1-2 months. Abraham et al. (82 AJ 87, 532) reported a search for short term variability in four non-thermal radio sources. None of them showed any short term variability larger than 10%. Heeschen (82 IAU Symp 97; 84 AJ 89, 1111) showed that compact sources display a "flicker" in their cm emission with an amplitude of about 2% and characteristic time scale of a few days. Pustil'nik (82 Soobchch.Spts. Astrofiz. Obs. Vyp. 33, 28) searched for rapid variability ($t>1$ day) in the cm range in fourteen objects with continuous optical spectra. Variability was found in nine cases. Studies of radio variability of BL Lac objects are found in Aller et al. (82 IAU Symp 97) and Altschuler (83 AJ 88, 16). Rudnick and Jones (82 ApJ 255, 39), from an unbiased sample of 40 flat spectrum sources, showed that complex spectrum sources are highly variable, while the simple concave spectrum and the straight spectrum ones show little or no variability. A re-examination of light curves of variable sources has been presented by Legg (84 IAU Symp 110), who showed that bursts from different variable sources, though differing in time scale, have profiles of the same shape.

Detailed studies of the radio variability of specific objects were made by Pustil'nik et al. (Pis'ma Astron Zh 7, 547, trans. Soviet AJ 7: PKS 0757+100), Wills et al. (83 ApJ 274, 62: 1156+295), Kikuchi and Inoue (84 IAU Symp 110, 181: OJ 287), Johnston et al. (84 ApJ 377, L31: BL Lac), Bregman et al. (84 ApJ 276, 454: 0735+178), O'Dea et al. (84 ApJ 278, 89: 3C 84) and Dent et al. (83 Nature 306, 41: 3C 84). Some of these studies include comparison with variability in other wavelength bands.

Ekers et al. (83 AA 120, 297) have published results of a six-year program to monitor the 5 GHz flux of compact radio sources in nearby spirals and ellipticals, and of cores in extended double radio galaxies and quasars.

Studies of the so-called "low frequency variability", typically at $\nu < 1$ GHz are given in Fanti et al. (81 AA Sup 45, 61), Dennison et al. (81 AJ 86, 1604), Dennison et al. (84 ApJ 281, L55). Interpretation in terms of intrinsic variability can be found in Fanti et al. (83 AA 118, 171) and references therein; and by slow refraction effects in the interstellar medium by Rickett et al. (84 AA 134, 390) and by Shaperovskaia (82 Astron Zh 59, 246; Sov AJ 26, N.2).

Polarization - Several authors have made measures of integrated linear polarization at several frequencies for extragalactic radio sources (Simard-Normandin et al. 81 AA Sup 43, 19; Simard-Normandin et al. 82 AA Sup 48, 137; Perley 82 AJ 87, 859; Conway et al. 83 MNRAS 202, 813; Vallee 83 AA Sup 52, 125; Bignell and Vallee 83, ApJ Sup 53, 147).

Rotation measures are discussed by Simard-Normandin et al. (82 op.cit.) and Conway et al. (83 op.cit.). By using close-by frequencies, unambiguous rotation measures have been derived by Rudnick et al. (83 AA Sup 52, 317; 83 AJ 88, 518). Aller et al. (82 IAU Symp 97) presented new data on four sources which exhibit large amplitude rotation of the polarization position angle with time.

Circular polarization measures are presented by Ryle and Brodie (81 MNRAS 196, 567), by de Pater and Weiler (82 MNRAS 198, 747) and Komesaroff et al. (84 MNRAS, 208, 409). De Pater and Weiler estimate the magnetic fields by applying uniform synchrotron emission model to the measured circular polarization. Komesaroff et al. discuss different alternatives for explaining the circular polarization variations.

Structure of Radio Galaxies and Quasars - The last three years have seen exciting new synthesis observations from the VLA, MERLIN, Cambridge, Westerbork, Fleurs, Culgoora and Molonglo. The implications of recent synthesis data for source physics generally have been reviewed by Begelman et al. (84 Rev Mod Phys 56, 255) and for radio jets in particular by Bridle and Perley (84, Ann Rev AA 22, 319). Many observations relating to energy transport in extragalactic sources are discussed in the Turin Workshop on "Astrophysical Jets" (Reidel 82, ed. A. Ferrari and A. G. Pacholczyk), though much new work has appeared since this volume.

The traditional distinction between compact and extended sources is vanishing, as many high dynamic range maps have found extended emission around "compact" sources (e.g. Browne et al. 82 MNRAS 198, 673; Browne et al. 82 Nature 299, 788; Perley et al. 82 ApJL 255, L93; Ulvestad et al. 83 ApJ 266, 18; Schilizzi and de Bruyn 83 Nature 303, 26; Ulvestad and Johnston 84 AJ 89, 189; De Pater and Perley 84, ApJ 273, 64; Antonucci and Ulvestad 84, Nature 308, 617). A large fraction of strong extragalactic sources has both compact cores and some kiloparsec-scale or larger structure. The prominence of the cores relative to the larger structures varies by more than 10,000 to 1 from source to source. The success of relativistic flow models for the compact core-jets has encouraged "unified" models wherein this variation is attributed to differing inclinations of different sources to the line of sight.

Jets - Jets are detected in many weak radio galaxies, where they are normally fairly symmetric, i.e. "two-sided" (Bridle and Perley 84), and in a high proportion of sources in well-observed complete samples of extended QSRs, where they are always very asymmetric, i.e. "one-sided" (Owen and Puschell 84 AJ 89, 932; Neff and Brown 84 AJ 89, 195; Burns et al. 84 ApJ 283, 515). They are however relatively hard to detect in strong, edge-brightened radio galaxies (Bridle and Perley 84) though some clear examples are now known (e.g. Linfield and Perley 84, ApJ 279, 60; Perley et al. 84 ApJ 285, L35). Among powerful extended sources, the relative prominence of jets increases with that of their radio cores (e.g. Burns et al. 84; Saikia 84 MNRAS 208, 231). The intensity asymmetries, dominant magnetic field configurations and collimation (spreading rates) of detected jets all correlate with both core and total powers (Bridle 84 AJ 89, 979).

Galaxies and Clusters - Single dish observations have been made at numerous frequencies. Normal nearby galaxies have spectral index which lies in a very narrow range, $\alpha = 0.74\pm0.05$ (Gioia et al. 82 AA 116, 164; van der Hulst and Israel 83 AJ 88, 736). The thermal fraction of the radio continuum is low, generally below 40% of the total at 10.7 GHz. A study of samples of extreme blue galaxies (Heidmann et al. 82 AA 105, 188; Klein et al. 83 AA 117, 332) showed that these objects are significantly more radio luminous than the nearby (redder) galaxies.

Maps of galaxies at several frequencies enable the study of the morphology of the radio continuum and the separation of the thermal (free-free) and nonthermal emission components (M31--Beck and Gräve 82 AA 105, 192; Berkhuijsen et al. 83 AA 117, 141; M33--Berkhuijsen 83 AA 127, 395; NGC 253--Klein et al. 83 AA 127, 177; M51--Klein et al. 84 AA 135, 213; NGC 4258--Krause et al. 84 AA 138, 385; NGC 6946--Klein et al. 82 AA 108, 176). Linear polarization observations at high frequencies showed an unusually regular magnetic field structure along the spiral arms of nearby galaxies (M31--Beck 82 AA 106, 121; NGC 6946--Klein et al. 82 AA 108, 176).

Jenkins (82 MNRAS 200, 705) used the Cambridge 5-km array to study a complete sample of 34 bright E and S0 galaxies, showing that weak sources are confined within the optical galaxies while more powerful ones can attain sizes of several hundred kiloparsecs. Ulrich and Meier (84 AJ 89, 203) mapped 18 B2 radio galaxies at 5 GHz to isolate their radio cores, and found that the core luminosity correlated with the stellar optical luminosity. Burns and Gregory (82 AJ 87, 1245) studied a complete sample of 20 4C radio galaxies in poor clusters with the VLA at 1.4 and 5 GHz. They found a high rate of detection of radio jets in weak radio galaxies (cf. above), and found several examples of tailed structures, indicating that this morphology is not restricted to rich cluster environments. They found no clear correlation between the radio morphologies and (low-resolution) X-ray imaging of the clusters. Hanisch (84 AA 133, 192) surveyed 37 poor clusters at 1.4 GHz with the WSRT, but found no further examples of head-tail structure. A study of radio galaxies in 65 rich clusters using the WSRT at 1.4 GHz was begun by Fanti et al. (83 AA 105, 200; AA Sup 51, 179; AA Sup 52, 411).

Quasars - Several samples of extended quasars were mapped with the VLA. Owen and Puschell (84 AJ 89, 932) studied 26 quasars from the Jodrell Bank 966 MHz survey. Hintzen et al. (83 AJ 88, 709) mapped 117 QSRs (mainly at $z < 1.5$). Neff and Brown (84 AJ 89, 195) studied 60 quasars with known VLBI cores. Feigelson et al. (84 AJ 89, 1464) mapped 15 quasars from X-ray samples. Swarup et al. (84 MNRAS 208, 813) studied 31 of the largest quasars. Significant numbers of distorted structures suggesting interactions with ambient IGM have been found in these samples, as well as the one-sided jets mentioned above.

Survey Samples - Peacock and Wall (82 MNRAS 198, 843) completed a structural survey of a sample of 168 sources with 2.7 GHz flux densities >1.5 Jy, and showed that 44% of unresolved (mostly <5") sources have spectral indices >0.5. The VLA was used to map 237 sources from the GB2 survey with 1.4 GHz flux densities >0.55 Jy (Machalski et al. 82 AJ 87, 1150; Machalski and Condon 83 AJ 88, 143) and 126 with 1.4 GHz flux densities between 0.20 and 0.55 Jy (Machalski and Condon 83 AJ 88, 1591). Lawrence et al. (84 ApJ 278, L95) reported statistics of radio structure types and optical identifications with VLA snapshots of 602 MIT-Green Bank survey sources with 5 GHz flux densities >0.05 Jy.

The most detailed information on individual sources comes from high resolution studies of the biggest, brightest and nearest objects, so we highlight such work here.

Jets - Multifrequency studies of the jet in the radio galaxy NGC 6251 by Saunders et al. (82 MNRAS 197, 253) and Perley et al. (84 ApJ Sup 54, 292) showed variations in its spreading rate (implying that it is not free everywhere), lateral oscillations, and knot structure indicating local particle acceleration. Perley et al. also showed that the 3-D magnetic field in this jet is not axisymmetric, and found rotation measure gradients indicating a magnetoionic medium outside the jet but within the optical galaxy.

VLA observations of the jet in M87 at 0.1" resolution (Biretta et al. 83 ApJ 274, L27) discovered a sharp inner edge to Knot A and an overpressure relative to the surrounding X-ray gas over much of the jet, though the variable spreading rate of the jet argues that it is not free. The knot structures suggest that they are shocks in the outflow of M87. There is also evidence for absorption of the knot emission below 408 MHz (Charlesworth and Spencer 82 MNRAS 200, 933).

Multifrequency VLA mapping of the jet in Cen A by Burns et al. (83 ApJ 273, 128) showed that it could be thermally confined by surrounding X-ray gas, and revealed strong similarities between its radio and X-ray intensity distributions. This makes severe demands of particle acceleration mechanisms in the jet if its X-ray emission is interpreted as synchrotron emission. Culgoora and Molonglo maps of Cen A by Slee et al. (83 Proc ASA 5, 247) showed that the lobes have a 327 to 843 MHz spectral index of 0.7 while the jet region has a spectral index of 0.93--this goes against the general trend for jets to have flatter spectra than the lobes they enter, and also questions the synchrotron interpretation of the X-ray jet (though higher resolution observations below 1 GHz are desirable).

Hot Spots - Resolutions better than 0.5" are needed to characterize the hot spot properties of distant powerful sources (e.g., Schilizzi et al. 82 J. Astrophys. Astron. 3, 173). Two main classes of hot spots have been recognized in well-resolved powerful sources--compact flat-spectrum hot spots and more diffuse steep-spectrum spots. These may have similar total fluxes in the same source, but the compact spots have much higher energy densities and much lower total energies (e.g. Lonsdale and Morison 83 MNRAS 203, 833). One-sided radio jets, where these are visible, tend to point toward the most compact hot spot, though exceptions are known. Magnetic fields in hot spots generally lie parallel to the ridge lines of the hot spot emission (e.g. Swarup et al. 84 MNRAS 208, 813).

Some compact hot spots in quasar lobes have internal pressures that are too great to be directly ram confined assuming normal IGM densities and subrelativistic advance velocities (e.g. Lonsdale and Barthel 84 AA 135, 46). If such spots are supplied by jets that flow into them and stagnate, very high jet velocities and conversion efficiencies would be required for energy and momentum balance. The morphologies and spectra of these spots and of their lobes (which often contain larger, secondary hot spots) suggest that they may be emission from oblique shocks at which jet outflows are deflected rather than stopped (see also Lonsdale 84 MNRAS 208, 545), possibly alleviating these difficulties. Lonsdale and Barthel 84 also discuss how plasmoid models may provide acceptable alternatives.

Lobes and Trails - As with jets, the biggest and the brightest continue to reveal new details. Qualitatively new classes of non-relaxed structure have been found in radio lobes using the VLA--polarized filaments (Cyg A--Perley et al. 84 ApJ 285, L35), and highly polarized rings or shells (Her A--Dreher and Feigelson 84 Nature 308, 43; 3C310--van Breugel and Fomalont 84 ApJ 282, L35). The origins of these structures are unclear, but the rings suggest episodic events or instabilities in the plasma outflow from the nucleus to the lobes. The projected magnetic fields run parallel to the ridges of most of the filaments and rings. The prominence of the jets and lack of strong hot spots in the powerful source Her A is unusual, given the general power-morphology trends for extragalactic sources.

Van Breugel (82 AA 110, 225) mapped the spectral index distributions and magnetic field configurations in the jets and outer regions of the radio galaxies 3C31, 3C66B and 3C129 with the WSRT (see also van Breugel and Jaegers 82 AA Sup

49, 529). He found a peculiar Faraday depolarization and rotation at the base of the jet in 3C66B which may be due to foreground magnetoionic material in the parent galaxy (cf. NGC 6251 above). Strom et al. (83 AA 122, 305) also used the WSRT to study the depolarization dichotomy between the North and South lobes of 3C31, suggesting large differences in the thermal densities on the two sides of the active nucleus. They found that the magnetic field, which is predominantly perpendicular to the inner jets, turns through 90 deg. to run parallel to the long axis of the outer lobes. Alexander et al. (84 MNRAS 209, 851) derived the spectral index distribution over the lobes of Cyg A from multifrequency mapping and concluded that if some aspects of this are attributed to synchrotron aging of material flowing away from the hot spots, their velocity of advance should be about 0.05c.

WSRT studies of the largest known rich cluster source (1919+479) by Robertson (84 AA 138, 41) were consistent with buoyant shaping of its large scale "wide angle tail" (WAT) structure, but neither buoyancy, gravitational bending nor dynamic pressure could account for the bent structure observed in 3C465 with the VLA by Eilek et al. (84 ApJ 278, 37) and at Cambridge by Leahy (84 MNRAS 208, 323). There is disagreement over whether motions of the parent galaxies through their clusters are large enough to explain the detailed shapes of this and other WATs. Galaxy velocities of order 500 km/s are required to produce the observed WATs by moving a twin jet away from static trail emission deposited in an earlier stage of its evolution, but it is unclear whether these are consistent with other constraints on the galactic velocities and with the ages of the radio trails estimated from observed spectral steepening (cf. Eilek et al. 84 and Leahy 84).

Symmetries and Orientations - New examples of sources with bends or S symmetry suggesting precessional or rotational motion of the primary collimator have been found, mainly in QSRs (Gower and Hutchings 82 ApJL 253, L1; Hunstead et al. 84 MNRAS 207, 55; Gower and Hutchings 84 PASP 96, 19; Muxlow et al. 84 IAU Symp 110, 141) but also in one radio galaxy (Condon and Mitchell 84 ApJ 276, 472). Specific precessional models fitted to these sources are generally complex and their parameters are not yet obligatory. Lonsdale (84) found morphological and spectral symmetries in 3C196 that are consistent with physical rotation of its primary collimator followed by outflow of material from the most compact hot spots. The total intensity symmetries of the lobes of powerful doubles are often broken at high resolution but it is not clear whether this favors alternating-ejection models for all such sources (Rudnick and Edgar 84 ApJ 279, 74; Ensman and Ulvestad 84 AJ 89, 1275).

Observations of 3C218 (Hyd A) at Fleurs by Simkin and Ekers (83 ApJ 265, 85) showed an edge darkened radio structure (unusual for a source of its relatively high power) elongated along the optical rotation axis of the galaxy, confirming a trend shown by other powerful radio galaxies. Kapahi and Saikia (82 J. Astrophys. Astron. 3, 161) discuss a possibly related alignment between the radio elongations and the optical minor axes in radio galaxies with prominent nuclear cores. Jaegers (83 AA 125, 172) documented three parallel edge-darkened sources in the field of 3C130, all possibly identified with galaxies; he suggested that this parallelism may reflect alignments among the three galaxies resulting from common membership in a cluster.

Steep Spectrum Cores (SSCs) - MERLIN and VLA maps of 3C380, a powerful edge-darkened source (also violating the general power-morphology trend) has been shown to have a complex extended structure (Wilkinson et al. 84 Nature 308, 619). Van Breugel et al. (84 AJ 89, 5) give VLA maps of 23 SSC sources; they find low degrees of polarization and misalignments between the core components and more distant lobes. These results suggest that SSCs manifest strong interactions between radio emitting plasma and dense ISM on a sub-galactic scale, analogous to those seen in radio Seyfert galaxies (e.g. NGC 1068--Wilson and Ulvestad 83 ApJ

275, 8) and studied in detail in some nearby radio galaxies with extranuclear line emission and small distorted radio sources (Heckman et al. 82 ApJ 262, 529; van Breugel et al. 84 ApJ 276, 79 and ApJ 277, 82).

VLBI - The Proceedings of IAU Symposium No. 110, "VLBI and Compact Radio Sources" (1984, eds. Fanti, Kellermann, and Setti) contains many up-to-date accounts of research relevant to this section, as does the earlier Proceedings of IAU Symposium No. 97, "Extragalactic Radio Sources" (1982, eds. Heeschen and Wade), and the review on "Compact Radio Sources" (81 Kellermann and Pauliny-Toth, An Rev Astron Astrophys 19, 373). Matveyenko (81 Radiophysics Institute, Gorki) has published a bibliography of VLBI papers published during the period 1965-1981.

Superluminal Sources - From 7 to 10 superluminal sources now are known; the number depends on the degree of certainty required by different authors (Cohen et al. 84 Proc IAU Symp 110, 95; Porcas 83 Nature 302, 753). Another half-dozen or more are suspected of being superluminal, but more data are needed for confirmation. The best cases are 3C120, 3C273, and 3C345 which are strong and are frequently observed at many wavelengths. Each of these has a bright, marginally unresolved "core" which is optically thick at centimeter wavelengths and whose flux density is constant to within a factor 2. Components move away from the core and travel along a similar track (forming a "jet" or "beam") with apparent velocity $v \sim 5c$ for Ho = 100. The highest well-determined value is $v = 9.5c$ for a component in 3C345 (Unwin et al. 83 ApJ 271, 536). In one source successive components may have somewhat different velocities. The beam is strongly curved and eventually points towards an outer jet (scale 100's of kpc). This is particularly vivid in 3C120 (Benson et al. Proc IAU Symp 110, 125) where there is continuity over most of the range from 1 pc to 100 kpc and a total curvature greater than 90°. The VLBI components evolve with a time scale of a few years; their spectra steepen and they grow weak.

Bartel et al. (Proc. IAU Symp 110, 113) have shown by astrometric measurements that the core of 3C345 is stationary with respect to NRAO 512, and thus that the jet components are indeed moving. The newest component in 3C345 was first detected at about 0.3 mas from the core in 1981, and moved to about 1.0 mas by early 1984. It accelerated in the midst of this journey. Its track has been nearly straight but not radial, although with enough (unseen) curvature at small distances it could have come out of the core (Moore et al. 83 Nature 306, 44; Biretta et al. 83 Nature 306, 42). The jet is best defined in 3C345 because 3C120 and 3C273 have low declination and poor north-south resolution. In 3C345 new jet components have almost overtaken the position old ones held at the beginning of these programs, and in the next few years it will be seen whether the tracks are the same or not. There already is some evidence that the two outer components of 3C345 are on different tracks (Cohen et al. 83 ApJL 269, L1).

4C39.25 is unique in that the centroids of its two components are approaching each other rather than separating. However, it is still possible to interpret this in terms of the birth of an unresolved new component which is separating from its parent, rather than as a contraction (Shaffer 84 Proc IAU Symp 110, 135).

Subluminal or Stable Sources - Only a few compact sources are known to be subluminal or stable. 3C84 is complex but contains a core-jet structure with a component moving at about $v = 0.2c$ (Romney et al. 84 Proc IAU Symp 110, 137). Stable sources include NRAO 150 (Baath et al. 80 AA 86, 364), 2134+004 (Pauliny-Toth et al. 84 Proc IAU Symp 110, 149), and the nucleus of M87 (Reid et al. 84 Proc IAU Symp 110, 145).

Relativistic Beams and Unified Schemes - The most common explanation for the superluminal motion involves a relativistic beam of Lorentz factor γ propagating at a small angle θ to the line of sight (Begelman et al. 84 Rev Mod Phys 56, 255). VLBI measurements of angular size and spectrum, plus Compton X-ray measurements, allow the calculation of a limit to the Doppler (blue-shift) factor δ of the beam, and this plus the superluminal motion sets constraints on θ and γ. In this way Unwin et al. (83 ApJ 271, 536) found $\gamma > 7$, $\theta < 7°$ for 3C345 ($H_o = 100$). Calculations of beam parameters based on the X-ray flux and a measured diameter are independent of the Hubble constant. Marscher et al. (81 ApJ 249, 406) used these calculations to successfully predict superluminal motion in NRAO 140, but this did not work for 3C147 (Simon et al. 83 Nature 302, 487; Preuss et al. Proc. IAU Symp 110, 29; Simon et al. 83 Proc IAU Symp 110, 111).

In the relativistic beam theory the radiation from a moving component is anisotropic and is boosted by about δ^2. This makes a strong selection effect which explains why such a large fraction of strong core-dominated sources are superluminal. There has been considerable speculation over the identity of the "misdirected" beamed sources, which must be 50 times more numerous than the directed ones. Scheuer et al. (79 Nature 277, 182) discussed the radio-quiet quasars in this context; see also Kellermann et al. (83 Proc Liege Colloq 24, 81) who showed that the radio weak quasars have the distribution expected from randomly oriented beams. Orr et al. (82 MNRAS 200, 1067) discussed the unification of superluminal sources and blazars with the common extended double sources. This point of view is strongly supported by the observation of large low-surface-brightness features (which could be outer lobes of doubles seen end-on), around many core-dominated objects (Schilizzi et al. 83 Nature 303, 26; Browne et al. 82 Nature 299, 788). All the superluminal sources except 3C273 have outer structure which surrounds (or is on opposite sides of) the core, but in 3C273 the outer structure consists solely of a linear straight jet on one side. Two superluminal sources (3C179 and 3C279) have outer structure of the conventional double-lobe type. Other tests of the beaming model have been reported (Kapahi and Saikia 82 J Astroph & Astron 3, 465; Kaikia and Wiita 82 MNRAS 200, 83).

Surveys - Two VLBI mapping surveys of flux-limited samples are underway. Pearson et al. (84 Proc IAU Symp 110, 15) have been making a survey of sources with S(5GHz) $\geq$ 1.3 Jy, $\delta > 35°$, and $b > 10°$. 45 of the 65 sources have VLBI structure and were mapped at 6 cm. These can be divided into 6 categories of which the most numerous (13/45) have the asymmetric core-jet structure. Second-epoch observations are now underway (Readhead et al. 84 Proc IAU Symp 110, 131). Two of 5 objects reobserved at 6 cm show structural variations. Observations at 10 GHz and at optical wavelengths are also being pursued.

Eckhart et al (84 Proc IAU Symp 110, 65) are studying flat-spectrum sources with $\delta > 70°$ and S(5GHz) > 1 Jy. VLBI observations are being made at many wavelengths, and larger-scale maps from MERLIN and VLA are being obtained. Four of the 13 sources were observed twice at 6 cm, and one showed structural variations.

Zensus et al. (84 AA 133, 27) detected 56 of 57 flat spectrum sources at 5GHz and fit simple models to the data. Romney et al. (84 AA 135, 289) have made first-epoch maps at 1.7 GHz of 21 low-frequency variables.

Detection surveys at 2.3 GHz have been made by Preston et al. (83 ApJ 269, 387) on a complete flux-limited sample selected from the Parkes ±4° catalog, by Wehrle et al. (84 AJ 89, 336) on sources in the ecliptic, and by Morabito et al. (83 JPL TDA Progress Report 42-74, 183) on south polar sources. In all these the limiting detectable flux was about 0.1 Jy. Matveyenko et al. (82 Soviet AJ 8, 77) have studied 3C84 and 3C345 at 18 cm wavelength. Fringes were detected in 18 cm observations using the 100 m antenna in Bonn FRG and a 6 m antenna in Shanghai, PRC.

Steep-Spectrum Sources - Many compact steep-spectrum sources show VLBI structure which is severely distorted on scales of 1-10 kpc. Wilkinson et al. (84 Proc IAU Symp 110, 25) show maps of four objects and suggest that the distortions might be due to interaction between a jet and interstellar gas. Fanti et al. (84 Proc IAU Symp 110, 25) show maps of 8 objects.

Compact doubles are a minority of all compact steep spectrum sources with turnover frequency near 1 GHz (Phillips et al. 82 AA 106, 21; Hodges et al. 84 AJ 89, 1327). Maps have been published at 1.6 GHz (Phillips et al. 80 ApJ 236, 89), 2.3 GHz (Phillips et al. 83 ApJ 271, 32), and 5 GHz (Mutel et al. 84 ApJ, in press; Pearson et al. 84 Proc IAU Symp 110, 15; Spangler et al. 83 ApJ 271, 44). Phillips et al. (82 AA 106, 21) suggest that these sources arise when a double-sided beam, advancing into the interstellar medium, is seen near the plane of the sky.

Nearby Galaxies - Studies of nearby galaxies have only recently become possible, because they are weak, with $L \sim 10^{40}$ erg s^{-1}. VLBI detection and/or model-fitting experiments are reported by Bartel et al. (82 ApJ 262, 556), Hummel et al. (82 AA 114, 400), Jones et al. (82 ApJ 261, 422), Preston et al. (83 ApJ 266, L93), and Preuss and Fosbury (83 MNRAS 204, 783). The data have warranted mapping for NGC 4278 (Jones et al. 82 ApJ 261, 422), M87 (Reid et al. 82 ApJ 263, 615), NGC 2911 and NGC 4278 (Schilizzi et al. 83 AA 126, 412), MK 348 (Neff and de Bruyn 83 AA 128, 318), and NGC 1052 (Jones et al. 84 ApJ 276, 480).

Wehrle et al. (84 ApJ 284, 519) made a detection survey for cores in a complete sample of 26 elliptical galaxies with $m_v \leq 16.5$ and S(408 MHz) $\geq$ 0.25 Jy. Thirteen had S_{core}(2.3 GHz) $\geq$ 2mJy.

Lensed Objects - VLBI observations play an essential role in the study of gravitational lensed objects, as they place the tightest constraints on the lens models. Two of the five known lens systems have been studied with VLBI: 0957+561 (Porcas et al. 81 Nature 289, 758; Gorenstein et al. 83 Science 219, 54), and 2016+112 (Gorenstein et al. 84 BAAS 15, 936). The images are particularly weak and require elaborate signal processing with phase referencing.

<u>Extragalactic Molecules</u> - High resolution CO mapping of other galaxies is hindered by the low signal level. High resolution, fully sampled maps of covering many beam areas are just now becoming available (see the review of Morris and Rickard 82 Ann Rev 20, 517 for previous results). The first maps showed little sign of spiral structure (Rickard and Palmer 81 AA 102, L13; Scoville and Young 83 ApJ 265, 148), for which sufficient spatial resolution is available. New CO maps of M51 made with the Onsala telescope (Rydbeck et al. 82 IAU Symp 100, 53) and the Caltech interferometer, however, show such structure. In the case of the Onsala data, a smooth background must be subtracted to clearly show the spiral arms in the disk which are 20%-30% of the spread-out CO emission. It has generally been assumed that the J = 1-0 transition of CO in galaxies (and the Galaxy) is optically thick. For M82, there is conflicting information from comparisons of observed temperatures in the J = 1-0 and 2-1 lines, but isotope ratios (Stark and Carlson 84 ApJ 279, 122) seem to support an effective low optical depth in the J = 1-0 line.

<u>Extragalactic Masers</u> - Extragalactic H_2O maser sources were found in NGC 1068 (M77), NGC 4258 (M106), M82, and NGC 6946 by Claussen et al. (84 Nature 310, 298) and in the Circinus galaxy by Gardner and Whiteoak (82 MNRAS 201, 13P). The NGC

1068 source, the most luminous H_2O maser known, is 350 times more luminous than the sun, assuming isotropic emission. Extragalactic OH masers were discovered in the LMC by Haynes et al. (81 MNRAS 197, 23P) and in IC4553 by Baan et al. (82 ApJL 260, L49). The latter source is more than 10^7 times stronger than the Milky Way source W3(OH) assuming isotropic emission.

Extragalactic Hydrogen - The detection of HI in early type galaxies is a game of patience but positive detections do reward the persistent. HI seems to be more abundant in low luminosity ellipticals (Lake and Schommer 84 ApJ 280, 107) but there is no dependence on environment (Dressel et al. 82 ApJ 259, 55). The availability of new broad bandwidth capabilities promises the detection of very broad HI signals, from massive rotating disks.

The comparative HI content of normal galaxies in varying environments was the subject of a workshop held at Green Bank in April 1982. In the Virgo Cluster, spirals are not only HI deficient (Giovanardi et al. 83 ApJ 267, 35) but the HI disks are also shrunken with respect to their counterparts in the field (Giovanelli and Haynes 83 AJ 88, 881). Virgo continues to provide fertile territory for investigation. In other clusters, comparison with the field produces mixed results (Bothun et al. 82 ApJ 87, 725; Giovanelli et al. 82 ApJ 262, 442).

Huchtmeier (82 AA 110, 12) reported on a survey of HI in Sa galaxies, while Schneider et al. (83 ApJL 272, L1) claim the detection of a massive intergalactic HI cloud.

The 21 cm line is a useful tool in deriving the redshifts for spiral galaxies to a z of about 0.03. The new feed at Arecibo will cover the frequency range to 1300 MHz. The compilation of Bottinelli et al. (82 AA Sup 47, 171) is most useful. The surveys that are currently underway promise clues to the large-scale structure of nearby superclusters, the stability of groups, and the use and calibration of the Tully-Fisher relation. The study of the orientation of spin vectors with the large scale structure (Helou and Salpeter 82 ApJ 252, 75) will constrain theories of galaxy formation. The number of detected highly redshifted absorption lines continues to grow and nearby quasars are also seen to show the emission signatures of rotating disks. The continuing acquisition of luminosity distances for galaxies, especially in the southern hemisphere, will provide increasing accuracy in the determination of the local motion (Hart and Davies 82 Nature 297, 191).

The last three years have been characterized by a steady flow of thorough HI studies with the WSRT and the first spectral line results of the VLA. Some of the highlights are summarized here, many results are more fully described in IAU Symposium 100.

The velocity fields of normal spiral galaxies show large-scale symmetric deviations, interpreted as oval distortions or kinematical warps; rotation curves are flat out to large distances, indicating that M/L increases outward (Bosma 81 AJ 86, 1791,1825). Studies of nearly face-on spirals show that this dark material is distributed in the halo's of the galaxies and not in a flattened disk (van der Kruit and Shostak 81 AA 105, 351; 84 AA 132, 20; AA 134, 258). A study of the rotation curves of binary galaxies shows that 50 to 80% of the mass of spirals is non-luminous (van Moorsel 82 PhD Thesis, Un. of Groningen).

An HI study of M31 with a linear resolution of 80x120 pc has been completed (Brinks 84 IAU Symp 100, 23). Holes are found in the HI distribution in the same area as the HII regions, OB associations, etc. On a large scale the HI layer shows a warped gas distribution similar to our own Galaxy.

With the continued improvement of the sensitivity of the WSRT at 21 cm it has become possible to study galaxies with smaller HI emissivity. The majority of the observed lenticulars has the HI in a ring outside the optical body (van Woerden et al. 83 IAU Symp 100; Knapp et al. 84 AA 133, 127). The HI in 2 spindle-like galaxies coincides with the outer optical components. The velocity fields suggest that these annuli have formed recently (Schechter et al. 84 MNRAS 208, 111).

Since the spectral line system of the VLA has become operational it is possible to observe a larger Declination range. This has resulted in the systematic studies of barred spirals. An interesting example is NGC 3992, which appears to have a flat rotation curve and yet no massive halo (Gottesman et al. 82 ApJ 260, 65). The good instantaneous UV coverage of the VLA makes it possible to map in spectral line snapshot mode. An example is an HI survey of the Virgo cluster (van Gorkom et al. 84, Clusters and Groups of Galaxies, p261, ed. F. Mardirossian), which shows convincingly the effects of ram-pressure sweeping in the center of the cluster.

Both the VLA and WSRT appear to be extremely suitable to study HI in radio galaxies, because of the high spectral dynamic range that can be achieved (van Gorkom and Ekers 83 ApJ 267, 528). The results indicate that in the majority of the cases hydrogen is falling toward the nucleus of these galaxies (Shostak et al. 83 AA 119, L3).

Some further radio studies have been made of HII regions in other galaxies (Viallefond et al. 83 AA 119, 185; Cersosimo and Loiseau 84 AA 133, 93). New searches for RRLs from active galactic nuclei and quasars have been made (Bell et al. 84 AA 130, 1), and further work has been done on the prospects and potential applications (Dravskikh and Parijskij 81 Sov AJ 25, 274; Val'tts 83 Sov AJ 27, 18; Shaver 83 Liège XXIVe, 287; Sarazin and Wadiak 83 AA 123, L1; Wadiak et al. 83 ApJ Sup 53, 351).

SETI

SETI research has made impressive progress in recent years. From the first radio search by Frank Drake in April, 1960, there have been at least 45 different searches (25 in the last six years), with about 130,000 hours of observations, in at least seven different countries (USA, USSR, Australia, Canada, France, Germany, Holland) with Japan getting ready to join.

Besides the SETI directed, short-term radio searches, there are also shared or parasitic SETI projects, such as the SERENDIP program of UC-Berkeley, which share and/or analyze data obtained for other purposes. There are also SETI dedicated facilities which are automated to operate continuously and account for the bulk of the observing hours logged so far. The two major ones are: the Ohio SETI Program (R. Dixon and J. Kraus) at Ohio State University in operation since 1973 and Project Sentinel (P. Horowitz) at Harvard.

A major development program for mega-channel spectrum analyzers and signal recognition algorithms is now in progress with potential uses in many other areas. Horowitz is building a narrow band (350 kHz), 8.4 million channel spectrum analyzer to be incorporated in 1985 to his project Sentinel at Stanford. Peterson and Linscott are building an 8 MHz, 8 million channel spectrum analyzer, which, together with the algorithms now being developed by B. Oliver at NASA-Ames, will become the cornerstone in the long-term SETI program of NASA that will include comprehensive all-sky and targeted radio searches over a wide frequency range.

Appendix A

RADIO ASTRONOMY

IN

CHINESE OBSERVATORIES

Prof. Wang Shou-Guan was kind enough to prepare an extensive report on Chinese radio astronomy which I have included in this privately circulated report. The highlights of the Chinese research are included in the main body of the report which will be published in the IAU Transactions. - *KIK*

RADIO ASTRONOMY IN CHINESE OBSERVATORIES
1982 - 1984

Instrumentation - Three major projects of radio astronomical instrumentation are being carried out in China. They are:

1. *The VLBI set-up at Shanghai Observatory:* (1) A VLBI station in Shanghai, China will be equipped with a 25 meter radio telescope and is scheduled to be completed in 1986. After the Shanghai-Effelsberg VLBI experiment (a 6 metre radio telescope was employed at Shanghai) which recorded successfully 14 radio sources, (2, 3) Shanghai Observatory went on to the acquirement of a Mark III terminal, and building of a new hydrogen maser and more low noise receivers which will finally cover the frequency bands of 1335-1740, 2175-2425, 4745-5240, 7900-8600, 10156-11150 and 22000-24000 MHz.

This project, when completed, will be used on astrophysical as well as a number of astro-geodynamical programmes.

2. *The 232 MHz Aperture Synthesis Telescope at the Miyun Station, Beijing Observatory:* (4) The Miyun synthesis telescope, Beijing Observatory, was put into service in October, 1984. This is a 16 x 12 element E-W array spanning 1164 meters, and at present, working at 232 MHz frequency. The synthesis pattern gives a resolution of $3'\!.8 \times 3'\!.8 \csc\delta$. A polar region "dirty map" obtained in 2 x 12 hours shows a dynamical range of 100:1, where sources of 0.2 Jy are easily detected. The thermal noise-limited sensitivity of the system is about 0.05 Jy. With a field of view of 8° x 8°, it will be used for source survey of sky region $\delta \leq +30$ and a number of other astronomical programmes.

3. *13.7 meter millimeter wave telescope of the Purple Mountain Observatory:* Building of the telescope by ESSCO company and the Nanjing Astronomical Observatory is in progress. The meticulously selected site at the Chaidamu Basin 3000 meters above sea level is under construction. Radiometers for 3 mm and 4 mm wavelengths have been completed. Spectrographs of various types and feeders and front ends for 13 mm and 2.6 mm wavelengths are being made. This telescope will be ready for observation in 1986.(5 - 11)

Besides these major projects, at the Yunnan Observatory a 10 meter radio telescope has been installed,(12) and a high resolution acousto-optical spectrograph has been developed by Wang J. S.;(13) at Beijing Observatory, Hu C. M. devised a phase stable transmission line for microwave interferometry by employing a "two path method",(14) Hun W. J. studied the influence of ionosphere on the visibility function of a meter wave interferometer.(15, 16) Yuan H. R. et al. at Nanjing University have studied methods for calibration of the antenna parameters.(17, 18) At the Purple Mountain Observatory, Chu H. S. investigated in detail the physical process of receiving signal of a polarized source by antenna.(19)

Solar Radio Astronomy - Daily patrol of solar radio emission at wavelengths ranging from 8 mm to 20 cm has been carried out regularly at 7 observatories and stations in Beijing, Nanjing, Kumming and Urumuqi; methods adopted and results of observation have been published in various circular and journals, and in the "Chinese Solar and Geophysical Data."

Data obtained during the total solar eclipse occurred at Yunnan on February 16, 1980 have been analyzed, e.g. (20, 21, 22). Main results were reported in (23).

A new result of 460 MHz interferometer records of type I solar radio bursts was reported by Liu X. Z. et al.,(24) and the Nanjing University group has studied the mechanism of type IV bursts.(25 - 27) Models of solar radio sources and events have been investigated by groups in Beijing(28, 29, 30) and in Purple Mountain Observatory.(31, 32, 33, 34).

Phenomena of millisecond microwave spike bursts observed on 10 cm wavelength have been reported by the Beijing Observatory group(35, 36, 37, 38) and theoretical studies were made at Nanjing University by Li C. S. et al.(39)

Cosmic Radio Astronomy

Molecular Astronomy - Various maser sources and CO clouds were investigated by the group of Beijing Normal University (Fan Y., Sun J. and others).(40 - 44) At Purple Mountain Observatory, Xiang D. L. studied life-time of molecular clouds,(45, 46); Zeng Q., making use of some molecular spectra, studied the physics and dynamics of the clouds, and stellar maser sources were also studied by this group.(47 - 51) Xin J. and others of Beijing University derived the physical parameters of molecular cloud from NH_3 data and by observations of NH_3 spectra analyzed the physics of the cloud and its exciting star.(52, 53)

Radio astronomy of galactic objects - Wu X. J. and Qiao G. J. of Beijing University made statistical and theoretical studies of pulsars.(54 - 60) Ma E. et al., using the Westerbork telescope, studied the morphology and nature of 3C58.(61)

Extragalactic Radio Astronomy - Yin Q. F. of Beijing University collaborated with D. S. Heeschen and J. Heidmann, studied clumpy Irr. galaxies and compact radio sources; by using the VLA, they mapped MK 7,8,33 and 297 at 2.6 and 20 cm wavelengths. Results are presented in (62 - 66). He also observed over 270 radio sources with the NRAO 140-ft and 300-ft telescopes. Some variable sources were found.(67, 68) Ma E. et al. observed 3C391.3 at 0.6 GHz with the Westerbork telescope;(69) Chen et al. mapped two southern radio galaxies at Fleurs;(70) Qian S. J., using the Cambridge telescopes, studied the hot spots of DA240 and Cyg A.(71-73) He also made some theoretical approach to the physics of jets and superluminous motion of extragalactic objects.(74, 75, 76) Fang L. Z. of the University of Science and Technology, by identifying quasar of flat spectra with optical objects, investigated the correlation between their radio and optical luminosities.(77) Chu Y.Q. of the same group analyzed the orientation of double sources for the testing of cosmology.(78) Some theoretical studies of radio sources were carried out by You S. H. of the same group.(79, 80)

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