40. Radio Astronomy (Radio Astronomie)

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INSTRUMENTATION

Aperture Synthesis Telescopes - Commissioning tests and observations have been made using three antennas in the Australia Telescope (AT), spaced up to 2km apart, and the first image of a radio source observed at 6cm was produced in 1989. The IRAM millimeter array in France comprizing three 15-m antennas has been commissioned at 3mm. A fourth antenna is planned as well as operation at 1mm. The three element Berkeley-Illinois-Maryland Array (BIMA) at Hat Creek is being expanded to six 6-m antennas and a new correlator with 1024 channel up to 830MHz bandwidth. Plans to expand to 9 antennas are final. The Owens Valley three-element millimeter array has been operated at 1mm, the shortest wavelength for the radio interferometry; a digital correlator with 500MHz bandwidth is under construction and the array will be extended to 6 antennas. In Japan at NRO the Nobeyama Millimeter Array equipped with SIS receivers and 320MHz bandwidth "FX" correlator is now operational at 3mm and 7mm wavelengths. New SIS receivers for 1mm and 2mm are under construction and a sixth 10-m antenna is planned. The Cambridge 5-km telescope, now the Ryle Telescope, has been substantially upgraded. The overall sensitivity of the instrument is being increased by a factor of ~20. The Giant Metrewave Radio Telescope, being built at Khodad near Pune in India, has made considerable progress and is expected to be operational by 1992-93. The new radio heliograph at Nobeyama for which funding was approved recently, will be the most important instrument for the future solar radioastronomy. A T-shaped array of 80 80-cm antennas will produce 10" images of the sun at 17GHz every 50ms. A dense 8x8 array of 2.4-m antennas at 10GHz with a digital system to synthesize images in real time are under construction in Waseda University, Japan. A submillimeter array with six 6-m antennas is in the design phase at the Harvard Smithsonian Astrophysical Observatory. A possible site is Mauna Kea in Hawaii or Mt.Graham in Arizona. Longer-range projects have been proposed: a Millimeter Array having 40 8-m antennas with 3-km maximum baseline by NRAO in the United States; a Large Millimeter Array having 30 10-m antennas with about 1km maximum baseline by NRO in Japan; and a Radio Schmidt Telescope having 100 12-m antennas in an array about 2km in extent by the Dominion Radio Astronomy Observatory in Canada.

Single Dish Radiotelescopes - The most dramatic event was the collapse of the NRAO 300-ft telescope in November 1988. A special grant from the US government will enable NRAO to build a 100 m replacement telescope in Green Bank. The dish diameter will be about 100m. The basic design study was finished by mid 1990 and

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the telescope should become operational in 1995. It will have an unblocked aperture and is planned to operate at the longer millimeter wavelengths. A further upgrade of the Arecibo telescope has been funded. A Gregorian subreflector system in a 25 m diameter radome will improve the efficiency and beam quality, especially at the higher (up to 8 GHz) frequencies. Most new single dish telescopes are dedicated to mm- and submm-astronomy. A notable exception is the 32 m antenna, built in Cambridge, England by Jodrell Bank as an extension of MERLIN and station of the European VLBI Network. This telescope will operate well at 7 mm and should be commissioned in the fall of 1990. The 14 m mm-telescopes in China (Purple Mountain Obs.) and Korea (Daeduk Radio Astr. Obs.) have gone into operation at 3 mm wavelength. Several submillimeter telescopes have reached a full operational state, while being improved through intensive activity in measuring and setting the paneled surfaces. Invariably some radio frequency (often called "holographic") technique has been applied, leading to reflector accuracies between 30 and 70 μm. These new instruments are listed in the following Table, as well as several telescopes, whose performance will be significantly improved.

Carbon-fiber reinforced-plastic (CFRP) is increasingly used in the new telescopes. CFRP was first used for the subreflector of the IRAM 30-m, main reflector of the Nobeyama 45-m, and the panels and part of the support structure of the IRAM 15-m telescopes on Plateau de Bure. CFRP is used extensively in the SMT, allowing unimpaired operation in daytime. A next step in technology will be the 2.7 m lightweight telescope of SOFIA (Stratospheric Observatory for Far-Infrared Astronomy), a collaboration between NASA and Germany, and perhaps Italy planned for 1996.

Telescope	Location	Altitude (m)	Diameter (m)	Accuracy (μm)	Operation (GHz)
SEST (Sweden,ESO)	La Silla	2400	15	50	230
JCMT (UK,NL,Can)	MaunaKea	4050	15	30	500
CSO (Caltec,Texas)	MaunaKea	4050	10.4	27	500
KOSMA (Un.Cologne)	Gornergrat	3150	3	50	350
SMT (MPIfR,Arizona)*	Mt.Graham	3180	10	15	850
NRAO	Kitt Peak	1940	12	(shaped subref)	350
IRAM (MPG,CNRS)	PicoVeleta	2780	30	70	350
MPIf Radioastronomie	Effelsberg	370	100	300	50
Haystack (MIT)	Westford	146	37	500	43

* SMT is planned for operation at the end of 1991.

Synthesis Imaging - Cornwell (1988, IEEE Trans. AP-36,8,1165-1167) has introduced a novel principle for the design of correlation arrays, based upon the maximization of the distance between samples across the Fourier plane. Imaging of very large objects with interferometric arrays has been limited by their small field of views and missing short spacings. A scheme of mosaicing, based on Maximum Entropy method to combine single dish with interferometer data has been developed by Cornwell (1988 A&A **202**,316-321). The radioastronomical seeing and its effects on interferometric imaging have been studied extensively for both troposheric and ionospheric effects on short- and long-wavelength interferometric observations, respectively (see Proc. IAU/URSI Symp. on Radioastron. Seeing, 1990, ed. Baldwin & Shouguan, Pergamon). Self-calibration/closure phase techniques have been successfully used in many cases of aperture synthesis observations (see Cornwell 1989, Science **245**,263-269). One-dimensional image-correlation analysis has been applied to image reconstruction using the Miyun Meter-wave Aperture Synthesis Radiotelescope (MSRT): see M. Wei (1988, A&A **190**,362-366). A new approach to the problem of wide-field mapping with non-coplanar baselines has been developed for the Cambridge Low Frequency Synthesis Telescope by Waldram and McGilchrist (see Rees 1990 MNRAS **244**,233). A technique has been used for reducing the grating lobes of the Molonglo Observatory Synthesis Telescope (MOST) during large-field synthesis (Amy and Large, 1989, Proc.Astr.Soc. Australia **8**,308).

SOLAR SYSTEM RESEARCH

The Sun - The Very Large Array (VLA) continues to be the dominant instrument for solar radio research at centimeter (2-20cm) wavelengths. Other major used over the past three years are the Owens Valley Radio Observatory (OVRO) frequency agile interferometer in the range of frequencies 1-18GHz, the Berkeley-Illinois-Maryland Millimeter Array (BIMA) at 3mm wavelength, the Nobeyama Radio Observatory solar array at 17GHz, and the Nancay radioheliogrsph operating at five frequencies in the range 140-450MHz.

VLA studies of active regions at 2 and 6 centimeters have shown that magnetic fields of ≥1800 Gauss can exist in the corona (White et al. 1990, EOS **71**,586). The Coronal Magnetic Structures Observing Campaign (CoMStOC), a collaboration designed to study magnetic fields in the corona has resulted in a better understanding of the generating mechanism of active region emission. On the theoretical side, Zheleznyakov and Zlotnik (1988, Soviet Astron.Lett.**14**,195) discussed the importance of detecting cyclotron lines in active regions and of direct determination of magnetic fields in the corona. The VLA observations of coronal bright points at 6 and 20cm have resolved the structure; there is time variability on scales of a few minutes (Kundu et al. 1988, ApJ **325**,905). Microwave structure of the quiet Sun has been mapped by Gary et al. (1990, ApJ **355**,321) showing stronger emission associated with closely spaced magnetic bipoles and weaker emission associated with supergranulation network. Microwave evidence has been provided by Kundu et al. (1989 ApJ **336**,1078) for large scale changes in the corona following a filament eruption. Millimeter and centimeter emissions associated with an eruptive prominence have been studied by Zodi et al. (1988 Solar Phys.**116**,83). A survey of the relative locations of the sources of microwave and hard X-ray emission using the WSRT and SMM data has been conducted by Alissandrakis et al. (1988 A&A **195**,290). Using the OVRO frequency agile system, Staehli et al. (1989 Solar Phys.**120**,351) showed that a significant fraction of microwave bursts show evidence for multiple spectral components. At meter-decameter wavelengths, the emphasis has been on understanding the radio signatures of coronal mass ejections (CME's) (Gopalswamy and Kundu, 1987 Solar Phys.**114**,347; Gopalswamy and Kundu, 1989 Solar Phys.**122**,145), with particular reference to slow CME's and slow-mode shock acceleration of electrons responsible for radio emission (Kundu et al. 1989, ApJ **347**,505). Using multifrequency imaging observations, magnetic field structures in moving type IV bursts have been determined (Gopalswamy and Kundu, 1989, Solar Phys.**122**,145). Microbursts at meter-decameter wavelengths have been interpreted as spontaneously emitted Langmuir waves by electron beams (Thejappa et al.1989, IAU Symp.**142**). The quiescent corona has been mapped at 90cm using the VLA by Lang et al. (A&A **199**,325), showing no systematic association with any optical couterpart, including active regions, filaments etc. Noise storm radiation at 90cm has been studied by Wilson et al. (1990 ApJ **350**,856). Three dimensional structures of coronal streamers, holes and CME plasmoids have been studied by Kundu et al. (1989 Adv.Space Rec.**9**,41) using Clark Lake multifrequency imaging observations.

Comets - The interest in comet observations, stimulated by the last approach of comet Halley continued. Reviews of the radio observations, especially comet Halley, were given by Crovisier and Schloerb, and by de Pater et al., in: *Comets in the Post-Halley era*, 1990, edited by Newburn et al., Kluwer, Dordrecht.

Lately four comets have passed the earth with observing conditions as least as good as those for comet Halley. In comet Brorsen-Metcalf, HCN was detected at 89GHz line and probably at 266 line; H_2CO was marginally detected at 226GHz with the IRAM 30m telescope (Colom et al. 1989, IAU Cir 4852. While monitoring the OH line at 1667MHz at Nancay the source B2 1426+29 was occulted by comet Okazaki-Levy-

Rudenko. During the occultation the line intensity doubled and the line width decreased significantly (Bockelee-Morvan et al. 1989, IAU Cir 4882). Observations of comet Austin with the IRAM 30m telescope resulted in the detection of HCN at 89 and 226GHz, of H_2CO at 226GHz, of H_2S at 169GHz and of CH_3OH at 145GHz (Bockelee-Morvan et al. 1990, IAU Cir 5020, Crovisier et al. 1990 IAU Cir 5022, Despois et al. 1990, IAU Cir 5027. In comet Levi the following molecular lines were found: HCN at 89 and 266, and 354GHz, H_2CO at 226 and 352GHz, H_2S at 169 and 217GHz, and CH_3OH at 97, 145, 165, 219, and probably at 242GHz (Schloerb and Ge 1990, IAU Cir 5081 and 5086, Colom et al. 1990, IAU Cir 5087).

Continuum - The mm-telescope of IRAM in Spain and the JCMT in Hawaii together with the new bolometer receivers, made it possible to detect thermal emission of comets Halley, Brorsen-Metcalf, Okazaki-Levy-Rudenko, and Austin (Altenhoff et al. 1989 A&A **222**,323; Luu&Jewitt 1989 IAU Cir 4914; Altenhoff et al. 1990, IAU Cir 4993). The range of signals varied from a low value, corresponding to balck body emission of a nucleus of 10km diameter, to a high value, explained by a grain halo with a total crosssection equivalent to a disk of ~40km diameter. For comet Brorsen-Metcalf the change from low to high signal happened within 1 day, comet Austin changed from high to low (unknown time scale), comet Halley showed a high signal for at least one week, possibly for several months.

The asteroids Ceres, Pallas, Vesta, and Hygiea were re-observed with the VLA at 2 and 6cm. Mm observations yield brightness temperatures close to those expected for a rapidly rotating black body at the same distance from the sun. Microwave observations of these asteroids yield temperatures 20 to 25% lower. This wavelengths dependence could be explained by a layer at least 3 to 8cm of finely divided dust, covering these asteroids (Webster et al. 1988, AJ **95**,1263; Johnston et al. 1989 AJ **98**,335). The decrease of observed brightness temperatures with the change from mm- to microwaves is due to a decrease of emissivity. Single frequency microwave observers should take into account an emissivity of 0.8 of asteroids for their physical interpretation (Webster & Johnston 1989, Publ.Astron.Soc.Pac.**101**,122).

Modern bolometers near 1mm wavelength on the IRAM telescope and the JCMT brought a breakthrough in sensitivity: about 20 asteroids were observed in the radio range for the first time. The threshold of sensitivity would allow to increase the number of radio detection easily by one order of magnitude, if a sufficient accuracy of the ephemerides were available.

GALACTIC RESEARCH

Galactic Continuum Surveys - New data of the large scale Galactic radio emission have become available: Ellis and Mendillo (1987, Aust.J.Phys.**40**,705) observed the southern sky at 1.6 MHz with 25° angular resolution and Strukov and Skulachev (1987, Pis'ma Astron. Zh.**13**,469; 1988, Sov. Astron. Lett.**13**,191) discussed 37 GHz observations with 5°.5 angular resolution. A spectral index map of the northern sky has been calculated from surveys at 408 MHz and 1420 MHz (Reich & Reich 1988 A&A Suppl.**74**,7). The map has 2° angular resolution and shows significant systematic variations of the spectral index across the sky. Close to the Galactic plane the non-thermal spectrum is steeper towards the center than the anticenter. The flattest spectra are seen at 40° to 50° Galactic latitude in the anticenter direction. The data are not in agreement with a static or purely convective halo of the Galaxy; there is qualitative agreement with cooling-convection halo models (Reich & Reich 1988 A&A **196**,211).

A survey of large sections of the northern Galactic plane with an unprecedented angular resolution of 13' x 11'.1 at 30.9 MHz was carried out with the Clark Lake telescope (Kassim 1988 ApJ Suppl.**68**,715). The results are presented in the form of contour maps and flux densities for 702 discrete emission regions have been listed. A systematic high resolution survey of the northern Galactic plane at 408 MHz and 1420 MHz using the DRAO telescope is in progress (Higgs 1989, J. R. Astron. Soc. Can.**83**,105). The first two sections of this survey have been published (Green 1989

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A&A Suppl.**78**,277; Joncas and Higgs, 1990, A&A Suppl.82,113). The maps have ~4' and 1' resolutions at 408 MHz and 1420 MHz respectively; lists of compact sources are included. Handa et al. (1987, Publ. Astron. Soc Jpn.**39**,709) have mapped the Galactic plane between $355^\circ \leq l \leq 55^\circ$ and $|b| \leq 1\overset{\circ}{.}5$ at 10 GHz with an angular resolution 3'. The flux densities for 144 small diameter sources are given.

A VLA snapshot survey at 1.5 GHz along the Galactic plane from $0^\circ \leq l \leq 90^\circ$ has been made by Garwood et al. (1988 AJ **96**,1655). 471 compact objects have been found. An excess of sources for $l < 40^\circ$ results from compact components of HII regions. Excluding these sources the authors found that the source counts agree well with those for extragalactic sources. High resolution VLA observations of the structure of variable sources in the Galactic plane have been reported by Duric et al. (1987 AJ **93**,890) and by Duric and Gregory (1988, AJ **95**,1149). Optical identifications are not available so far for most of the observed sources, but are necessary to distinguish galactic from extragalactic sources. Condon et al. (1989, AJ **97**,1064) made a sensitive source survey at 4.85 GHz with the NRAO 91-m telescope; this includes most of the northern Galactic plane.

<u>Radio Stars</u> - More observations have been undertaken at higher and lower frequencies to better determine source spectra. Variability has been found for nearly all groups of stars. About 140 papers reporting new observations appeared during the period covered; references can be found in the updated version (March 90) of Wendker's radio star catalogue (1987 A&A Suppl.**69**,87).

The simple conversion of one-frequency-one-epoch radio flux density measurements is not adequate for OB and WR type stars. Nearly one third show contamination by nonthermal emission at any given time (Bieging et al. 1989 ApJ **340**,518; Hogg 1989 AJ **98**,282). The chance of contamination seems to increase with luminosity (Bieging et al.) or with peculiarity for later types (Taylor et al. 1987 MNRAS **228**,811; Drake et al. 1989 ApJ **322**,903; Felli et al. A&A **217**,179; Phillips and Lestrade 1988 Nature **334**,329). The distinguishing property is a slow variability. There is also a slight indication in the data collected by Wendker (l.c.) that the radio spectra of freely expanding winds often deviates from the canonical index of -0.67. The nonthermal emission appears to be synchrotron radiation outbursts and source sizes are similar to the stellar size (Felli et al. l.c.) The WR star AS 431 was found to be a radio double (Moran et al. 1988 Nature 340,449).

Pre-main sequence stars (PMS) have been found by now to exhibit 3 different spectral components: free-free emission resulting from an expanding stellar wind, nonthermal low frequency outbursts and thermal radiation of warm dust at high frequencies. More than one of these are often present simultaneously. Nonthermal outbursts occur at random and may originate both as synchrotron or gyrosycnrotron radiation in tangled magnetic fields. Only a small fraction of the stars seem to be active as multiple surveys of the ρOph (Stine et al. 1988 AJ **96**,1394) and CrA clouds (Brown 1987 ApJ **322**,L31) have shown. Convincing evidence that warm dust dominates the mm-spectrum of PMS was first given for HL Tau by Sargent et al. (1989 ApJ **323**,L131).

Activities of red dwarf flare stars have been extensively monitored. Although general surveys show that strong flaring is quite rare (Bastian et al. 1988 AJ **95**,794) many individual flares have been studied. Substructure in a flare of AD Leo (Güdel et al. 1989 A&A **220**,L5) and a brightness temperature of 10^{13}K of a low frequency flare of YZ CMi (Kundu & Shevgaonkar 1988 ApJ **334**,1001) prove that the emission mechanism is a coherent process. Peculiarities of the spectral shape were found indicating either a low and high frequency component (Güdel and Benz 1989 A&A **211**,L5) or a curved spectrum (Large et al. 1989 Proc.Astr.Soc.Australia **8**,123). Despite searches, a correlation of flaring activities with other stellar parameters has not been found, but one with stellar rotation may be present (White et al. 1989 ApJ Suppl 71,895). Dynamic spectra of flares display a bewildering amount of substructure (Bastian et al. 1990 ApJ **353**, 265).

Observations of so-called active binaries (RS CVn, FK Com, Algol-like binaries etc.) have been vigorously pursued. Surveys (Slee et al. 1987 MNRAS **229**,659; Morris and Mutel 1988 AJ **95**,204) and monitoring individual systems indicate that up to

40% of them are active at a given time. Progress in modelling these nonthermal phenomena offers the prospect of using these activities to deduce properties of the magnetic field involved (Melrose 1987 Springer Lecture Not.Phys. **291**,83). High resolution data give sizes of the emitting region comparable to that of the binary system (Lestrade et al. 1988 ApJ **328**, 232; Massi et al. 1988 A&A **197**,200). The most recent observations (Drake et al. 1989 ApJ Suppl **71**,905) give some evidence that the tangled magnetic fields are generated by the rapid rotation of one of the binary components. A survey of classical novae (Bode et al. 1987 MNRAS **228**,217) has shown that the nonthermal shell around GK Per (latest mapping by Seaquist et al. 1988 IAU Colloq.**101**,47) appears to be unique. Whereas all these active binaries show nonthermal phenomena, symbiotic stars seem to emit partially optically thin thermal radiation which may be proportional to the mass loss rate of the red giant component (Seaquist and Taylor 1990 ApJ **249**,313). VLBI observations of the recurrent nova RS Oph may indicate the presence of a core-halo structure (Taylor et al. 1989 MNRAS **237**,81).

Unexpectedly, red giants and supergiants have shown clear signs of nonthermal flaring. Abbout one third of a sample of stars closer than 30pc exhibited variable emission (Slee et al. 1989 MNRAS **239**,913). The discovery of 6cm variability of α Ori (Bookbinder et al. 1987 Springer Lecture Not.Phys. **291**,337) may point to similar phenomena.

For very exotic objects (like SS433) progress has been rather slow. The jet of CH Cyg was confirmed (Taylor et al. 1988 ASSL **145**,231), R Aqr's jet is 2-sided (Kafato et al. 1989 ApJ **346**,991), AE Aqr behaves like a mini-Cyg X-3-source (Bastian et al. 1988 ApJ **324**, 431), and Cyg X-3 itself was found to have a broad double lobe structure (Strom et al. 1989 Nature **337**,234).

Radio stars are used in astrometry to study the extragalactic reference link with galactic stars (Lestrade et al. 1988 AJ **96**,1746; White et al. 1990 AJ **99**,405).

Recently indications for warm dust emission from middle and late type dwarfs have been found at mm-wavelengths (Chini et al. 1990 A&A **277**,L5).

Dust emission - The IRAS survey has shown that many classes of objects emit a large fraction of their energy at FIR wavelengths indicating the presence of a considerable amount of dust. The new generation of submm telescopes have provided exciting results for continuum radiation from cold dust. This radiation provides a new way for determining gas masses and gives the opportunity to detect protostars or circumstellar disks.

i) star formation: The search for early stages of star formation has revealed several cold and dense cloud cores within large molecular complexes like NGC2024 (Mezger et al. 1988 A&A **191**,44) and OMC1,2 (Mezger et al. 1990 A&A **228**,95), harboring a number of so-far-unknown condensations. These are explained in terms of isothermal protostars. Observations of more advanced phases of stellar evolution has shown that the initially spherical distribution of circumstellar dust becomes flatter and condenses into a massive cold disk (Mezger et al. 1987 A&A **182**,127). The extension of these disks are perpendicular to the bipolar outflow of ionized gas (Neckel et al. 1989 A&A **210**,378).

ii) circumstellar disks: Submm studies of T Tauri stars give strong evidence that more than 40% of these pre-main sequence objects are surrounded by spatially thin circumstellar disks of 0.001 to $1M_\odot$ with larger-than-normal dust grains (Beckwith et al. 1990 AJ **99**,924). Similarly Vega-type main sequence stars show an excess of submm radiation, originating from circumstellar disks with particle sizes larger than 10μm (Chini et al. 1989 A&A **219**,87). There seems to be a trend that with increasing stellar age the particle size grows whereas the disk mass, as shown by its dust emission, decreases. Both findings support an evolutionary scheme where circumstellar dust grains condense into larger conglomerations as preliminary phase of the formation of planets.

Pulsars - Recent conference proceedings concentrating on pulsar physics include *The Origin and Evolution of Neutron Stars* (1987, ed. Helfand and Huang, Reidel, Dordrecht) and *Timing Neutron Stars* (1989 ed. Ögelman and van den Heuvel, Kluwer, Dordrecht). General reviews are given by Backer (1988, Galactic and Extragalactic Radio Astronomy, ed. Vershuur and Kellerman, Springer Verlag, Heidelberg) and Srinivasan (1989 A&A Rev 1,209). Globular cluster, binary, and millisecond pulsars are reviewed by Backer and Kulkarni (1990 PhysToday **43**(3),26).

Globular clusters have been rich sources for the discovery of interesting pulsars. Wolszczan et al. (1989 Nature **337**,531) reported a pulsar in M15 with a negative period derivative, most probably due to acceleration of the pulsar toward us by the collapsed core of the cluster. Also in M15, Anderson et al (1989 IAU Cir 4772) have found a pulsar in a high eccentricity, 8 hour binary system which promises to be a useful laboratory for tests of general relativity. Lyne et al. (1990 IAU Cir 4974) have found a millisecond pulsar in Terzan 5 in a 108 minute binary orbit which is eclipsed behind its companion star for nearly half of each orbital period. A search in the radio nebula CTB80 resulted in the discovery of a young pulsar (Kulkarni et al. 1988 Nature **331**,50). Non-directed pulsar searches included one at Molonglo (D'Amico et al. 1988 MNRAS **234**,437) which found no new millisecond pulsars, and an Arecibo search in which the first eclipsing binary millisecond pulsar, PSR 1957+20 (Fruchter et al. 1988 Nature **333**,237)was detected. There are now just over 500 pulsars known, including 16 with periods less than 12ms, and 15 in binary systems.

Long term pulsar timing programs are continuing at a number of observatories. Stinebring et al. (1990 Phys.Rev.Lett. **65**,285) have reported on seven years of millisecond pulsar timing at Arecibo, placing upper limits on a gravity wave background near the predictions of cosmic string theories of galaxy formation. Dewey et al. (1988 ApJ **332**,762) measured the period derivatives and other parameters for 66 pulsars. Lyne et al. (1988 MNRAS **233**,667) summarize six years of Crab pulsar timing, and Cordes et al. (1988 ApJ **330**,847) discuss fifteen years of Vela pulsar timing, finding that period discontinuities are bimodally distributed: infrequent glitches and much more frequent "microjumps". Alpar et al. (1988 MNRAS **233**,25) interpret the large glitch in PSR 0355+54 in terms of the vortex-creep model. The first actual observation of a period jump in Vela (Hamilton et al. 1989 IAU Cir 4708) showed that the speed-up occurred in less than two minutes.

Taylor and Weisberg have continued their 15 year study of the binary PSR 1913+16 (1989 ApJ **345**,434). The decay of the orbit due to gravitational radiation is within 1% of the general relativistic prediction. Taylor and Dewey (1988 ApJ **332**,770) report better parameters for four binary pulsars, including the advance of periastron for PSR 2303+46. The companion of PSR 1957+20 has been detected optically (Kulkarni et al. 1988 Nature **334**,504; Fruchter et al. 1988 Nature **334**,686), with a light curve modulated by a factor of three to five over the binary orbit. Kulkarni and Hester (1988 Nature **335**,801) have discovered an Hα emission nebula around PSR 1957+20, attributed to shocks drived into the interstellar medium by a relativistic wind from the pulsar. The ablation of this companion star by the pulsar has generated considerable theoretical interest; observational and theoretical details are discussed by Fruchter et al. (1989 ApJ **351**,642) and references therein.

Average profile observations enjoyed renewed interest. An extensive review by Lyne and Manchester (1988 MNRAS **234**,477) of all available mean profile and polarization data leads to a number of conclusions on the two-dimensional form of radio beams. The phenomenological emission model has been extended with a study of the geometry of the core region (Rankin 1990 ApJ **352**,247). Biggs et al. (1988 MNRAS **235**, 255) have searched for interpulses and emission bridges in 38 southern pulsars; they report evidence that magnetic fields tend with age toward alignment with spin axes. Excess delays beyond those expected from cold plasma dispersion are reported at decameter wavelengths for some pulsars (Shitov et al. 1988 Sov Astron Lett **14**,181), and attributed to sweepback of the magnetic field lines at high altitude. Phillips and Wolszczan (1990, *Low Frequency Astrophysics from Space*, ed. Weiler & Kassim, Springer Verlag, Heidelberg) find no such behavior, however.

Stinebring and Condon (1990, ApJ **352**,207) completed an extensive study of refractive interstellar scintillation of a number of pulsars. Gwinn et al. (1988 ApJ **334**, L13) used VLBI techniques to resolve the scattering disk of PSR 1933+16. Observations of 17 pulsars led Kuz'min et al. (1988 Sov Astron Lett **14**,58) to conclude that the high frequency ν^{-4} dependence of scattering broadening weakens considerably at low frequency.

Radio Recombination Lines - Probably the most exiting new results in radio recombination line research were obtained at millimeter wavelengths. The discovery of time-variable maser radio recombination line emission in the H29α and H30α lines towards the binary system MCW 349 (Martin-Pintado et al. 1989 A&A **222**,L9) is a prime example of such exiting new work. It was found that over a time scale of half a year both the H29 and H30α line profiles change drastically, while the H41α line profile shows no variation.

Millimeter lines are also being used extensively to study the properties of compact HII regions. Gordon (1989 ApJ **337**,782) observed a number of HII regions in H and He 40α lines. The observed properties agree with predictions using the departure coefficients of Salem and Brocklehurst (ApJ Suppl **39**,633). From the data Gordon deduced a mean abundance of singly ionized helium of 10.3±3.1 % with a slow increase towards larger galactocentric radii. Wilson et al. (1987 A&A **186**,L5) reported on further millimeter radio recombination line observations of W3(OH). The data here suggest a "champagne" flow rather than the earlier suggested expanding spherical geometry.

Wood and Churchwell (1989 ApJ Suppl **69**,831) have studied a large number of ultra compact HII regions (diameters <0.1 pc, electron densities $>10^4 cm^{-3}$) in radio continuum and H76α radio recombination line emission at 0.4 arc sec resolution. The analysis of these and higher frequency radio recombination line observations of such UC HII regions showed that even in 3mm lines pressure broadening can be of influence on the line shapes.

Garay et al. (1989 A&A **215**,101) reported on H76 and H110α line observations of several Planetary Nebulae. In most, the H76α line appears to be emitted under near LTE conditions but in some cases locally stimulated emission is of importance. The H110α line towards IC418 is found to be collisionally broadened.

Stimulated carbon radio recombination line (RRL) emission was observed towards Cassiopeia A at lower frequencies (1989 Payne et al. ApJ **341**,890). The RRLs below 115 MHz were observed in absorption, above 200 MHz Carbon lines are observed in emission towards Cas A. These lines originate in cold, high density regions in the Perseus arm along the line of sight to Cas A. Further research on cold ISM was carried out by Vallee who has modelled molecular clouds near HII regions to explain the properties of observed CII and SII RRLs (1989 A&A **224**,191 and references therein).

The kinematics of the ionized gas in the Galactic center region was studied by Schwarz et al. (1989 A&A **215**,33). The H76α data suggest the presence of a ring with a radius of about 1.5 pc of ionized gas rotating at 100 kms^{-1}. Many filaments and clouds in the galactic center region are found to have velocities greater than expected for orbits around a central Black Hole or isothermal sphere. These high velocities can only be explained by invoking some acceleration process.

Yusef-Zadeh et al. (Proc. IAU Symp.**136**) report unusually broad H92α line emission towards HII regions near the galactic center. Most of this large line width is thought to be due to velocity shearing and microturbulence in the ionized gas.

Interstellar molecules - The period 1987-90 has been marked both by the coming into operation of several new single dish telescopes operating at mm and sub-mm wavelengths (notably the JCMT and CSO sub-mm instruments on Mauna Kea and the SEST telescope at La Silla) and the increased use of Interferometers for molecular line studies. The latter development mainly reflects increased receiver sensitivity at millimeter and short centimeter wavelengths. The combination of larger telesopes and improved receiving equipment has led among other things to the detection of several previously unknown interstellar species. Among the most interesting of these discoveries were those of several metal-containing species in IRC10216 (Cernicharo & Guélin 1987 A&A **183**,L10), of the first phosphorus containing species (Turner and Bally 1987 ApJ **321**,L75; Ziurys 1987 ApJ **321**,L81), SiC (Cernicharo et al. ApJ **341**,L25), cyclic C_3H (Yamamoto et al. 1987 ApJ **322**,L55) and CH_2CN (Saito et al. 1988 ApJ **334**,L113; Irvine et al. 1988 ApJ **334**,L107). Interestingly enough, the

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majority of these new detections were in two rather disparate sources: the circumstellar shell around the carbon rich giant IRC+10216 and the cold nearby dust cloud TMC1. Perhaps as a consequence, there have been considerable efforts to model the chemical processes in these regions (e.g. Herbst and Leung 1989 ApJ Suppl.**69**,271; Langer and Graedel 1989 ApJ Suppl.**69**,241). These models assume the chemistry to be solely influenced by gas-phase processes. There is evidence however that evaporation of dust mantles and processes on grain surfaces is important in certain regions such as the Orion-KL hot core (see, e.g. the account by Walmsley 1989 in Proc. of IAU Symp. **135**).

Improved receiver quality has also led to large-scale CO mapping. Examples are maps of a composite map of the Milky Way (Dame et al. 1987 ApJ **322**,706), and more detailed maps of the southern Coalsack (Nyman et al. 1989 A&A **216**,185), of the Cepheus region (Grenier et al. 1989 ApJ **347**,231) and of the galactic third and fourth quadrants (Bronfman et al. 1988 ApJ 324,248; May et al. 1989 A&A Suppl **73**,51). A summary of this work has been given by Thaddeus (1989 in "The Physics and Chemistry of Interstellar molecular Clouds", ed. Winnewisser and Armstrong, Springer Verlag, Heidelberg). In the same volume, Mebold has reviewed the high latitude clouds seen in CO, HI, and on the IRAS maps. A considerable amount of work has gone into combining existing CO surveys with data from other wavelengths such as IRAS,HI and Gamma ray maps. Examples are the studies of Mooney & Solomon (1988 ApJ **334**,L51) and that of Strong et al. (1988 A&A **207**,1). Reviews of the results from this type of analysis are given in articles by Bloemen and Boulanger in "The Physics and Chemistry of Molecular Clouds".

A determination of the strength of magnetic fields in interstellar clouds is fundamental. Zeeman splitting in masers is treated in the section on *Galactic Molecular Masers.* A large amount of work on 18cm OH (e.g Crutcher et al. 1987 A&A **181**,119; Goodman et al. 1989 ApJ **338**,L61) has somewhat improved the situation. One proposal is that magnetic fields play an important role in cloud support (Myers and Goodman 1988 ApJ **329**,392).

Higher angular resolution has led to many studies of fine structure within clouds. Our current knowledge of this topic has been summarized by Wilson and Walmsley (A&A Review 1989 **1**,141) and the particular case of the star forming region adjacent to the Orion nebula is reviewed by Genzel and Stutzki (1989 Ann.Rev.A&A **27**,41). The cloud structure is presumably intimately related to the incidence of star formation and a review of the current theoretical situation is given by Shu,Adams,and Lizano (1987 Ann.Rev.A&A **25**,23). The clumpy structure of the clouds has consequences for the degree of penetration of UV radiation and hence for cloud heating. Studies of high excitation tracers such as CO(7-6) have helped elucidate the nature of the ionized gas-molecular cloud interface (e.g Stutzki et al. 1988 ApJ **332**,379 and Schmid-Burgk et al. 1989 A&A **215**,150).

Molecular Outflows - Molecular outflows are energetic mass ejections everywhere from embedded infrared objects, or young stellar objects. Most CO emission of outflows is produced by gas moving with velocities of order 10kms^{-1}, but in some flows motions in excess of 100kms^{-1} are seen. It is likely that molecular outflows are the earliest observational signature of star formation we can see in dense molecular clouds. The total number of CO outflows is now ~150, among which ~100 is located within 1kpc of the Sun.

Efforts to search for CO outflows at mm-wavelength have been made in an unbiased way (Fukui 1989, in *Low Mass Star Formation and Pre-main Sequence Objects*, ed. B. Reipurth, ESO Garching, hereafter LMSF&PMSO) and IRAS based surveys in several nearby star forming regions; Taurus (Heyer et al. 1987 ApJ **321**,370) selected dark clouds (Schwartz et al. 1988 ApJ **327**,350; Parker et al. 1988 MNRAS **234**,67p), dense cores (Myers et al. 1988 ApJ **324**,907), luminous IR sources near the Galactic plane (Snell et al. 1988 ApJ **325**,853; 1990 ApJ **352**,139), low luminosity sources in dense cores (Tereby et al. 1989 ApJ **339**,222), and luminous sources/H_2O masers in Orion and other regions (Wouterloot et al. 1989 A&A **215**,131). In addition, optically selected 25 pre-main sequence objects were surveyed (Levreault 1988 ApJ **330**,97; 1988 ApJ Suppl **67**,283). These searches have revealed more low-mass

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outflows than before, reinforcing the idea that outflow is a phenomenon common to stars of various masses. The molecular outflow sources are distinguished by their luminosity excess. These authors interpreted that the large luminosity of the outflow sources is due to the gravitational energy released in the dynamical mass accretion onto the protostellar core. This may indicate that molecular outflows represent the main accretion phase of a solar mass protostar.

The most spectacular region of active star formation is in Orion and Monoceros. The region has been most intensively studied by the unbiased surveys of Fukui (1988 VistasAstron. **31**,217; LMSF&PMSO) and Margulis et al. (1988 ApJ **333**,316). Five outflows were found in Orion. As a result, the number of outflows has been increased by a factor of ~3 to ~40 in the whole Orion and Monoceros region.

Individual molecular outflows were studied with single dish telescopes for the following sources: ρOph A/VLA 1624−2418 (André et al. 1989 A&A **236**,180), L1689N/ρOph East/IRAS 16293−2422 (Wootten et al. 1987 ApJ **317**,220; Walker et al. 1988 ApJ **332**,335), L1551 IRS5 (Uchida et al. 1987, PASJapan **39**,907; Moriarty-Schieven et al. 1987 ApJ **319**,742; Fridlund et al. 1989 A&A **213**,310; Liljeström 1989 A&A **219**,L19; Rodriguez et al. 1989 ApJ **337**,712), HH7−11 (Liseau et al. 1988 A&A **192**,153), Cep A (Hayashi et al. 1988 ApJ **332**,354), NGC2071-North (Iwata et al. 1988 ApJ **325**,372), NGC2071 (Moriarty-Schieven et al. 1989 ApJ **347**,358), B335 (Hirano et al. 1988 ApJ **327**,L69), RNO43 and B335 (Cabrit et al. 1988 ApJ **334**,196), IRAS20188+3928 (Little et al. 1988 A&A **205**,129), B335 and L723 (Morarty-Schieven et al. 1989 ApJ **338**,952), L1641-North (Fukui et al. 1988 ApJ **325**,L13), NGC7538 (Kameya et al. 1989 ApJ **339**,222), Mon OB1 (Margulis et al. 1990 ApJ **352**,615, Margulis et al. 1988 ApJ **333**,316), GSS30 (Tamura et al. 1990 ApJ **350**,728), ρOph B3 (Loren et al. 1989 ApJ **338**,925), L1448/IRS3 (Bachiller et al. 1990 A&A **231**,174), GGD27 IRS (Yamashita et al. 1989 ApJ **343**,773), S87/IRS (Barson et al. 1989 A&A **345**,268), L1251 (Sato et al. 1989 ApJ **343**,773), Ori-I-2, L1206 and IC1396 (Sugitani 1989, ApJ **342**, L87), V645Cyg (Schulz et al. 1989 ApJ **341**,288), L1642 (Liljeström 1989, A&A **210**, 337), L673 (Armstrong 1989, A&A **210**, 373), and L1228 (Haikala 1989, A&A **223**, 287). A highly collimated, energetic outflow has been found 3' SW of Orion KL (Schmid-Burgk et al. 1990, A.S.A.G. **4**,34).

High resolution mapping is starting to reveal molecular distribution of outflow sources with angular resolutions of ≤10": or higher ρOph East (Mundy et al. 1990 ApJ **352**,159), HH7−11 (Grossman et al. 1987 ApJ **320**,356), OMC−1 (Masson et al. 1987 ApJ 319,446), Ori B (Barnes et al. 1990 ApJ **351**,176), NGC7538 IRS1 (Batrla et al. 1988 ApJ **330**,L67; Batrla et al. 1990 ApJ **351**,530), dense molecular cores (Tereby et al. 1989 ApJ **340**,472), and L1551 IRS5 (Sargent 1988 ApJ **333**,936)).

Several outflow sources were studied in radio continuum: (G35.2−0.74N (Heaton et al. 1988 A&A **195**,193), and L1551 (Rodriguez 1989 ApJ **337**,712)). In the infrared the following sources were studied: M8E-IR (Mitchell et al. 1988 ApJ **327**,L17), T Tau, DG Tau, L1551 IRS5, HH 7−11, HH 42A, and HH 43 (Cohen et al. 1988 ApJ **329**,863), Cep A (Doyon et al. 1988 ApJ **334**,883), and OMC1 (Brand et al. 1988 ApJ **334**,L103)). The 4.7μm CO absorption in M8E-IR appears to locate the warm component of the CO outflow (Mitchell et al. 1988 ApJ **327**,L17). Dense disks in L1551 IRS5 and B335-FIR were studied by Menten et al. 1989 A&A **223**,258), and dynamical interaction between outflows and dense cores are discussed in L43 and RNO 91 (Mathieu et al. 1988 ApJ **330**,385), and in Cep A (Torrelles et al. 1987 ApJ **321**,884).

Uchida et al. (1987, PAS Japan **39**, 907) made 20" resolution observations of L1551 IRS5 using the 45m telescope at Nobeyama. Their ^{12}CO maps show a velocity distribution consistent with CO lobes rotating at ~1kms^{-1}. The data also show that the CO lobes are apparently accelerated over 0.1pc near the driving source. These two features are also seen in ^{12}CO maps by (Moriarty-Schieven et al. 1988 ApJ **332**,364). At present, L1551 IRS5 is the only source that exhibits rotating CO lobes. These features are consistent with those predicted by the magneto-hydrodynamical models. In L1551 and some other outflows, the accelerated CO is concentrated along the walls of a relatively empty cavity.

Several sources have been found which exhibit broad 21cm HI lines (Lizano et al. 1988 ApJ **328**,763); this may be consistent with models in which the primary wind is mostly atomic. Very faint extremely high velocity CO (EHV) with a linewidth of order

~100-400kms/s has been observed towards some sources like HH7-11, GL 490, S140, MWC 1080, AFGL 490, and NGC2071 (Koo 1989 ApJ **337**,318; Margulis et al. 1989 ApJ **343**,779). This component of the outflow may trace a wind in which hydrogen is in atomic form but carbon has been partially converted into CO (Glassgold et al. 1989 ApJ **336**,L29). The number of EHV sources is 6 among 150 outflows, still a small fraction of the outflow sample at present. Five of the EHV sources are luminous, $L \sim 10^3-10^4 L_\odot$, and thus should be driven by high mass stars. HH7-11 has the lowest luminosity, $90L_\odot$. The observed ^{12}CO spectra show a discontinuity between the lower velocity ^{12}CO emission and the EHV ^{12}CO emission (Margulis et al. 1989 ApJ **343**,779), suggesting that they may have different origin. In case of HH7-11, a detailed mapping in ^{12}CO indicates evidence for interaction between high velocity gas and the low velocity molecular gas (Liseau et al. 1988 A&A **192**,153). A future sensitive mapping with high angular resolution is needed to determine the origin of the EHV. It is unclear which model can best explain acceleration of molecular outflows.

It has been suggested that molecular outflows represent an evolutionary phase earlier than T Tauri stars. A study of molecular outflows in dark cloud cores (Myers et al. 1988 ApJ **324**,907) suggests a trend of higher bolometric luminosities in CO outflow sources, although samples of outflows used were not statistically complete. Accounts of the evolutionary status of molecular outflows given for optically selected PMS objects (Levreault 1988 ApJ Suppl **67**,283), IRAS sources Wouterloot et al. (1989 A&A **215**,131) and H_2O masers (Snell 1990 ApJ **352**,139). These studies are not statistically complete, being biased towards luminous and perhaps more massive objects. A study of published data on outflows in various star formation regions did not find an evolutionary trend for molecular outflows (Berrilli et al. 1989 MNRAS **237**,1) The sample used by these authors is neither statistically complete, and the number of the outflow sample appears too small (e.g. a few outflows in Taurus).

Cloud support by outflows for three giant molecular clouds, Orion south, S287, and Mon OB1, indicate that 50-160 generations of molecular outflows are needed (Margulis et al. 1988 ApJ **333**,316; Fukui 1989 LMSF&PMSO). The time scale found, $\sim 2-5\times10^6$yr, is similar to the cloud free fall time estimated from typical ^{13}CO linewidths ~2kms/s and typical cloud sizes ~20pc. This suggests that molecular outflows play an important role in cloud support.

<u>Galactic Molecular Masers</u> - The study of cosmic masers is undergoing a renaissance. In the past three years important maser lines of CH_3OH, HCN, OH, NH_3, and SiO have been found. The number of known maser sources has doubled in the same period, largely as a result of targetted surveys of IRAS sources. There have been comparable advances in our theoretical understanding of masers. General accounts have been given by Reid & Moran (1988 *Galactic and Extragalactic Radio Astronomy* eds. Verschuur and Kellerman, Springer Verlag, Heidelberg, p.255), Cohen 1989 (Rep.Prog.Phys. **52**, 881) and Moran 1990 (*Handbook of Laser Science and Technology*, CRC Press). More specialized reviews of theory and observations appear in Proc. of IAU Symp **129**, particularly articles by Diamond (p.213), Kylafis (p.223) and Strelnitskij (p.239). Cataloges of maser sources have been published by Cesaroni et al. 1988 (A&A Suppl **76**,445), te Lintel Hekkert et al. 1989 (A&A Suppl **78**,399), and Engels & Heske 1989 (A&A Suppl.81,323).

The most important new maser line is the strong and widespread 183 GHz $3_{13}-2_{20}$ transition of H_2O (Cernicharo et al. 1990 A&A **231**,L15), which has been found in star-forming regions and in circumstellar envelopes. There are significant differences between the $3_{13}-2_{20}$ emission line and the $6_{16}-5_{23}$ emission line of H_2O at 22 GHz. A submillimetre water maser, the $10_{29}-9_{36}$ transition at 321 GHz has also been detected (Menten, Melnick & Phillips 1990 ApJ **350**,L41). Another important new maser is the 44 GHz 7_0-6_1 A^+ transition of methanol (Haschick, Menten & Baan 1990 ApJ **354**,556), which has already been detected in many star-forming regions. Other new methanol maser lines have been reported by Plambeck & Wright (1988 ApJ **330**,L61), Batrla & Menten (1988 ApJ **329**,L117) and Haschick et al. (1988 BAAS **20**,957). Methanol masers seem to be found exclusively in star-forming regions, never in circumstellar envelopes. Also in star-forming regions are time variable ammonia masers in the non-metastable (J,K)=(11,9) and (9,8) inversion transitions (Wilson & Henkel 1988 A&A **206**,L26; Wilson et al. 1990 A&A **229**,L1).

Most surveys for masers in star-forming regions have been based on the IRAS-data base, including surveys for OH 18 cm masers (Braz & Sivagnanam 1987 A&A **181**,19; Cohen, 1988 MNRAS **231**,205), H_2O 22 GHz masers (Braz & Epchtein 1987 A&A **176**,245; Wouterlout et al. 1988 A&A **191**,323; Braz et al. 1989 A&A Suppl.**77**,465; Scalise et al. 1989 A&A **221**,105; and Churchwell et al. 1990 A&A Suppl.**83**,119) and methanol 12 GHz masers (Kemball et al. 1988 ApJ **331**,L37). More traditional surveys have also been conducted for H_2O 22 GHz masers (Caswell et al. 1989 Aust.J.Phys.**42**,331) and methanol 12 GHz masers (Norris et al. 1987 ApJ **321**,L159; Koo et al. 1988 ApJ **326**,931). H_2O masers are being monitored for variability at many observatories (e.g. Liljestrom et al. 1989 A&A Suppl **79**,19; Abramyan et al. 1987 Astrofiz.Issel.Izo.Spets.Astrofiz.Obs.**24**,85; Peng 1989 A&A **216**,165). VLBI observations of the H_2O maser flare in Orion were reported by Matveenko (1989 Sov.Astr.Lett. **14**,468). Major interferometric studies of the relationship between OH and H_2O masers and compact HII regions have been published by Gaume & Mutel (1987 ApJ Suppl.**65**,193) and Forster & Caswell 1990 (A&A **213**,339). These have been complemented by detailed studies of individual sources, from which one of the most significant results is the evidence for maser discs around young stars on the 100-1000 AU scale (Plambeck et al. 1990 ApJ **348**,L65; Brebner et al. 1987 MNRAS **229**,679; Forster 1990 A&A **227**,L37; Johnston et al. 1989 ApJ **341**,847). The source W3OH has been mapped in several transitions of OH and CH_3OH (Baudry et al. 1988 A&A **201**,105; Menten et al. 1988 ApJ **333**,L83 and **331**,L41; Airapetyan et al. 1989 Sov.Astr.Lett.**15**,215 and **15**,175). As yet there is no simple explanation why particular transitions are excited in particular clumps. A highlight of VLBI mapping has been the measurement of proper motions of H_2O masers in the distant sources Sgr B2 and W49N. With models, these measurements yield a distance estimate to the galactic center (Reid et al. 1988 ApJ **330**,809; Gwinn et al. 1989 IAU Symp.No.**136**,p.47). OH proper motions in W3OH have also been reported by Bloemhof et al. 1987 (BAAS **19**,1094). VLBI measurements of maser spot sizes have also been used to study interstellar scattering (Kemball et al. 1988 MNRAS **234**,713; Gwinn et al. 1988 ApJ **330**,817).

In maser theory, Field & Gray (1988 MNRAS **234**,353) have presented a general treatment of the many-level radiative transfer problem, and applied it to OH. With the detection of the $^2\Pi_{1/2}$, $J=^3/_2$ and $^5/_2$ lines of OH (Wilson et al. 1990 A&A **231**,159) all microwave lines of OH within 500K of the ground state have been measured; the results will allow additional checks of OH maser pumping models. Pumping of H_2O masers in star-forming regions has been discussed by Kylafis & Norman (1987 ApJ **323**,346), Elitzur, Hollenbach & McKee (1989 ApJ **346**,983), Elitzur & Fuque (1989 ApJ **347**,L35), Sumin (1990 Sov.Astr.Lett.**15**,258), Anderson & Watson (1990 ApJ **348**,L69), and excitation of methanol masers by Zeng & Lou (1990 A&A **228**,480). The origin of maser polarization has been re-examined by Deguchi & Watson (1990 ApJ **354**,649) and Nedoluha & Watson (1990 ApJ **354**,660). These developments are timely in view of recent observational progress in the study of magnetic fields in star-forming regions, reviewed by Moran (1990 IAU Symp.No.**140**,p.301). Garcia-Barretto et al. (1988 ApJ **326**,954) have determined full Stokes parameters for OH masers in W3OH and investigated the three-dimensional structure of the magnetic field. Fiebig & Guesten (1989 A&A **214**,333) have detected circular polarization of water masers, which implies field strengths of up to 100 mG. Linear polarization of water masers was studied by Barvainis & Deguchi 1989 (AJ **1197**,1089), while variations in the linear polarization during the Orion water maser flare were studied by Garay et al. 1989 (ApJ **338**, 244) and Matveenko et al. 1988 (Sov.Astr.Lett.**14**,468).

For circumstellar masers, there have been particularly successful IRAS-based surveys which exploit the regular variation of infrared color with stellar mass-loss rate. By selecting candidate sources at different places along the infrared color sequence it is possible to optimize the detection rate of particular maser lines. Major surveys of this type for circumstellar OH, H_2O and SiO masers have been conducted by Eder et al. (1988 ApJ Suppl.**66**,183), Lewis & Engels (1988 Nature **332**,49), Gaylard

& Whitelock (1988 MNRAS **235**,123), Sivagnanam (1989 Ph.D. Thesis, Univ. of Paris), Gaylard et al. (1989 MNRAS **236**,247), Deguchi et al. (1989 MNRAS **239**,825), Galt et al. (1989 AJ **98**,2182), Likkel (1989 ApJ **344**,350), Hall et al. (1990 MNRAS **243**,480) and te Lintel Hekkert (1990 Ph.D. Thesis, Univ. of Leiden). Several of these authors discuss the infrared criteria for identifying OH-IR stars, and for optimizing the detection of particular types of star or particular maser transitions.

The IRAS surveys also revealed new types of circumstellar maser sources; most intriguing are the OH and H_2O masers (normally indicative of oxygen-rich envelopes) which are associated with carbon stars (Little-Marenin et al. (1988 ApJ **330**,828); Deguchi et al. (1988 ApJ **325**,795). The evolutionary status of these objects is hotly debated (Zuckerman & Maddelena 1989 A&A **223**,L20; de Jong 1989 A&A **223**,L23). Another class of objects has very broad OH emission, spanning 200 kms^{-1} and may be related to the bipolar mass-loss object OH231.8+4.2 (Likkel & Morris 1988 ApJ **329**,914; te Lintel Hekkert et al. 1988 A&A **202**,49). A third class of sources have OH1612 MHz emission and radio continuum emission, and are almost certainly at an intermediate stage between OH-IR source and planetary nebula (Pottasch et al. 1987 A&A **177**,L49; Zijlstra et al. 1989 A&A **217**,157). MERLIN maps of two of these objects confirm that the OH masers are the remnants of a normal 1612 MHz maser shell (Shepherd et al. 1990 Nature **344**,522).

More traditional surveys include a major study of OH maser emission from Mira variables by Sivagnanam (1988 A&A **206**,285) and Sivagnanam et al. (1989 A&A **211**,341), who discuss the criteria for OH emission and the OH properties of Miras. Searches for circumstellar H_2O masers have been made by Engels et al. (1988 A&A **191**,283) and Lindqvist et al. (1990 A&A 229,165). Vardya (1987 A&A **182**,75) has discussed the relation between the detectability of H_2O masers and the shape of the visual light curve for Miras. Comparison between optical and H_2O maser variability of Mira stars has been carried out by Kudashkina & Rudnitskij (1988 Perem. Zvezdy **22**,925) and Berulis et al. (1987 Astron.Tsirk.**1501**,3). Allen et al. (1989 MNRAS **236**,363) have detected new SiO maser sources associated with Mira variables and symbiotic stars. The prototype of this class is R Aqr. Evidence for a two-sided radio jet and a circumbinary SiO maser in this remarkable source was presented by Kafatos et al. (1989 ApJ **346**,991). Vibrationally excited SiO emission in the v=3, J=1-0 transition has been studied by Alcolea et al. (1989 A&A **211**,187). Variability of circumstellar SiO emission and its relation to the IR emission was discussed by Martinez et al. (1988 A&A Suppl.**74**,273) Bujarrabal et al. Planesas & Romero (1987 A&A **175**,164), and Alcolea et al. (1990 A&A **231**,431). New maser transitions of SiO have also been reported: the v=1, J=6-5 transition (Jewell et al. 1987, ApJ **323**,149); the SiO v=0, J=1-0 transition (Nguyen-Q-Rieu et al. 1988 ApJ **330**,374; Zhou & Kaifu 1988 Acta.Astr.Sin.**29**,253) and the SiO v=0, J=1-0 transition (Barcia et al. 1989 A&A **215**,L9).

The most important new circumstellar maser line reported is the (0,2,0) J=1-0 line of vibrationally excited HCN, which is observed at 89GHz in carbon-rich envelopes (Guilloteau et al. 1987 A&A **176**,L24). Strong HCN emission appears to be confined to stars with intermediate mass-loss rates. Time variability and linear polarization are observed (Lucas et al. 1988 A&A **194**,230; Goldsmith et al. 1988 ApJ **333**,873). Further maser transitions of HCN and $H^{13}CN$ have also been reported (Lucas & Cernicharo 1989 A&A **218**,L20; Izumiura et al. 1987 ApJ **323**,L81).

Many interferomeric studies of the structure of circumstellar envelopes have been carried out. OH 1612 MHz masers have been mapped by Welty et al. (1987 ApJ **318**,852), Bowers & Johnston (1988 ApJ **330**,339); and (1990 ApJ **354**,676) and Chapman (1988 MNRAS **230**,415). These authors discuss the degree to which the maser shells are spherically symmetric, and the constancy of the envelope structure, both of which are important for the phase-lag method of distance determination. Asymmetries in OH 1612 MHz emission were also discussed by Szymczak (1990 MNRAS **243**,375). Use of OH-IR sources for distance measurement was discussed by Cohe et al. 1989 (IAU Symp. No.**136**,p.51). Major programs to monitor OH 1612 MHz emission for phase-lag determination are underway at several observatories, and are expected to yield results in the coming triennium.

OH mainline emission from Mira variables has been mapped by Sivagnanam et al.

(1990 A&A **229**,171). VLBI hotspots have been observed in the envelope of U Her, including a blue-shifted feature which may be an image of the star itself. Such features could be used to align the radio and optical reference frames. Astrometric studies of OH and H_2O masers by de Vegt et al. (1987 A&A **179**,322) suggest that an accuracy of 0.1 arcsec is attainable. Absolute position measurements of SiO masers by Wright et al. (1990 AJ **99**,1299) gave somewhat larger discrepancies with the optical positions. There has been a major study of circumstellar H_2O masers by Lan et al. (1987 ApJ **323**,756), who confirm that the size of the H_2O maser region is correlated with the stellar mass-loss rate. VLBI and polarimetric observations of SiO masers in R Cas were presented by McIntosh et al. (1989 ApJ **337**,934). Circular polarization of circumstellar SiO masers has been reported by Barvainis et al. (1987 Nature **329**,613), which implies strong magnetic fields (10-100G) in the inner parts of the circumstellar envelope. Evidence from maser observations for stellar and circumstellar magnetic fields was reviewed by Reid (1990 IAU Symp.No. **140**,p.21). Finally it is notable that circumstellar masers in OH-IR sources are finding wider use in galactic astronomy as probes of the galactic potential in the galactic centre and the galactic bulge (Lindqvist et al. 1989 IAU Symp.No.**136**,p.503); te Lintel Hekkert & Dejonghe 1988 (*The Mass of the Galaxy*, CITA workshop, ed. M.Fich, Cand.Inst.Th.Astrophys.,p.8) .

<u>The Galactic Center</u> - IAU symposium No.**136** on *The Galactic Center* (ed. M. Morris, Kluwer, Dordrecht) was held during July 1988. Topics ranged from large-scale phenomena on kpc-scales to the most compact structures in the nucleus. Talks were presented on the distribution of gas, dust and stars across the central bulge, on mangetohydrodynamic features like the Arc and the Lobes, on the morphology of the Sgr A complex (East, West, halo), on the circumnuclear disk, and on the location and nature of sources in the innermost nucleus. Theoretical and observational evidence for a central mass condensation, its possible nature (black hole) and mass was discussed. For details, the conference proceedings, which cover most activities on this subject to mid 1988.

Since then, high-resolution dust continuum and atomic and molecular line maps of the giant molecular clouds just neighboring the nucleus have been published, revealing their clumpy nature and physical interaction with the galactic center (Okumura et al. 1989 ApJ **347**,240; Mezger et al. 1989 A&A **209**,337; Genzel et al. 1990 ApJ **356**,160). An intimate interaction of the Sgr A East non-thermal shell with the M-0.20-0.07 molecular cloud (the '+50km/s cloud') has been demonstrated. Pedlar et al. (1989 ApJ **342**,769) explored the morphology of the Sgr A (radio) complex, showing that the thermal component Sgr A West is clearly seen in absorption against the non-thermal emission from Sgr A East and hence must be in front of this region.

A series of papers related to the nature of the spectacular magnetohydrodynamic phenomena in the galactic center have appeared. A new system of non-thermal filaments was presented by Bally et al. (1989 ApJ **336**,173), resembling the prominent non-thermal continuum Arc filament (see Yusef-Zadeh et al. 1988 ApJ **329**,729) on the northern extension of this feature. The thermal emission from the arched filaments of the Bridge, that appear to connect the Arc with the Sgr A complex, is shown to arise from the ionized interfaces of massive molecular clouds. Possible excitation scenarios are discussed in Serabyn et al. (1987 A&A **184**,133), Morris et al. (1989 ApJ **343**,703) and Genzel et al. (1990 ApJ **356**,160). Sofue et al. (1989 ApJ **342**,L47) report evidence for a 4kpc long jet-like feature emanating from the galactic center region.

<u>Supernovae (SN) and supernova remnants (SNR)</u> - SN1986j and the prompt radio burst from SN1987a have been resolved by VLBI (1987 Nature **334**,412; 1989 ApJ **337**, L85), consistent with an origin in the interaction region between the ejected envelope and the progenitor's wind. The inferred brightness distribution of SN1986j implies anisotropies in either the ejecta or the circumstellar medium.

A detection of SN1987a (1990 A&A 227, L21) at 1.3mm in September 1988 probably represented free-free emission in the expanding envelope, although synchrotron emission from a central pulsar-powered nebula could not be ruled out

(1989 A&A **208**,L5). A non-detection 10 months later suggests considerable cooling and recombination between the epochs.

The VLA survey for radio emission from optically selected SNe continues (1989 ApJ **336**,421), yielding estimates and upper limits for progenitor mass-loss rates. High fidelity radio light curves have been obtained for SN1986j at wavelengths from 90-1.3cm (1989 ApJ **341**,883). A second component of non-thermal emission from SN1986j was detected at 1.3mm (88 proc. 22nd ESLAB symposium p.387). This had an inverted spectrum suggestive of an embedded pulsar-powered synchrotron nebula.

Three of the M82 hot spots have been detectd with VLBI (1988 ApJ **323**,505). A map of the brightest shows an elongated shell typical of a SNR. Analogous populations of compact radio sources have been found in the central regions of NGC 253 and NGC 4736 (1988 ApJ **330**,L97; 1988 ApJ **332**, L67). Other studies of extragalactic SNRs are described in 87 IAU Coll. **101**, p.289 and 1988 ApJ **329**,116.

Extended low-brightness SNRs and candidate SNRs continue to be discovered from single dish (1988 Proc. "SN shells and their birth events", ed. W. Kundt, Springer Verlag, Heidelberg, p.48 & 134; 1988 MNRAS **234**, 971) and compact interferometer array(1990 A&A **232**,207; 1988 ApJ Lett.**328**,L55; 1990 Proc. AS Austral **8**,274) surveys of the galactic plane. Preliminary results of a VLA snapshot survey sensitive to distant young SNRs are available (1990 ApJ **358**,485). FIR (1987 A&A Suppl **71**,63; 1989 AJ **98**,1358) and hydrogen recombination line (1989 ApJ **341**,151) brightnesses are commonly used to distinguish synchrotron from free-free emission, improving the selection efficiency for flat-spectrum SNRs. Flat-spectrum pulsar-powered "filled-center" SNRs could constitute a substantial fraction of all SNRs.

The formation of radio shells through the interaction of SN ejecta with the surrounding medium has been investigated by searching for shells around 4 young field pulsars with spin-down ages ranging from 20,000 to 40,000 yr (1988 ApJ **326**,751; 1989 ApJ **340**,355; 1987 IAU symp.**125**). Only one (very faint) shell was found, suggesting that synchrotron emission from shells is not a long-lived phenomenon.

There is evidence (1989 ApJ **346**,860) that the synchrotron emission of older SNR shells can be re-energized by a high velocity pulsar formed by the SN passing through the shell. This can explain some "composite" SNRs like CTB80 (1988 Nature **331**,50; 1988 Nature **334**,229; 1988 ApJ **331**,L121) in which a flat spectrum filled-centre remnant is embedded in a steep spectrum shell, and objects like G5.4-1.2 in which a compact source is connected to broad-scale structure by a thin bridge of emission. With the probable association of PSR 1800-21 with G8.7-0.1 (1990 Nature **343**,146) 6 SNR-pulsar pairings are now known. To date 23 SNRs are classified as filled-centre or composite (1988 AnnRev A&A **26**,295).

Many detailed continuum images of SNRs have appeared, including W50 (1987 AJ **94**,1633), 3C58 (1988 ApJ **327**,845), G296.5+10.0 & the SNR of SN1006 (1988 ApJ **332**, 940), Puppis A (1990 ApJ **350**,266), Cas A (1990 MNRAS **243**,87) and Kepler's SNR (2nd epoch; 1988 ApJ **330**,254). Convincing circumstellar interaction models have been given for Cas A (1989 ApJ **344**,332) and for Kepler's SNR (1987 ApJ **319**,885).

Mapping of SNRs in HI and/or CO (1-0) has provided morphological evidence for interactions with pre-existing cavities (1987 Sov. Astron. **31**,621; 1989 MNRAS **237**,277; 1988 Sov.Astron. **65**,573; 1989 ApJ **347**,231) and with interstellar clouds (1987 IAU Coll.101 p. 261,265; 1990 ApJ **351**,157; 1988 A&A Suppl **175**,363). However, with the exception of a shocked HI cloud in G166.0+4.3 (1989 MNRAS **237**,277), no evidence for velocity-broadened line profiles has been reported. In a sensitive survey (1989 MNRAS **238**,737) broad asymmetric OH absorption features were found in only 3 of a sample of 16 SNRs. The presence of hot dense material in IC443 has been confirmed in a detailed study of molecular abundances (1990 ApJ **341**,857).

Low frequency turnovers in the spectra of SNRs have been used as a probe of free-free absorption in the interstellar medium (1989 ApJ **347**,915).

EXTRAGALACTIC RESEARCH

Extragalactic Source Surveys - Several large-scale sky maps have been made with sufficient sensitivity and resolution to reach source densities $\sim10^4 sr^{-1}$. The low-frequency limit of such surveys has been significantly reduced by the 38MHz map (Rees 1990 MNRAS **244**,233) of the polar cap above $\delta=+60°$ with $4'.5 \times 4'.4 \mathrm{cosec}\delta$ resolution; ~5000 sources with $S \gtrsim 1$Jy were detected. The part II of the 6C survey at 151MHz (Hales et al. 1988 MNRAS **234**,919) covers the zone $+30° < \delta < +51°$, $08^h30^m < \alpha < 17^h30^m$ with $4'.2 \times 4'.2 \mathrm{cosec}\delta$ resolution. A total of 8278 sources were detected above 0.19Jy, from which the 151MHz source counts between 0.2Jy and 100Jy were estimated. The Univ. of Texas Survey is almost complete, covering $\delta > -35°$ at 365MHz. Nearly 7×10^4 compact sources stronger than S~0.25Jy were detected, and their positions have been measured with arcsec accuracy (Douglas 1987 BAAS **19**,1048). The NRAO 7-beam receiver was used on the 91m telescope to map 6.0sr in the declination range $0° < \delta < +75°$ at 4.85GHz with $3'.3 \times 3'.7$ resolution and 5mJy rms noise (Condon et al. 1989 AJ **97**,1064), and catalogs containing over 5×10^4 sources stronger than S~25mJy have been obtained from these maps.

Catalogs containing $\gtrsim 10^4$ sources are needed to detect statistically useful samples of optically or infrared-selected galaxies since only a small fraction of extragalactic sources are "local"($z<0.1$). Radio indentifications of IRAS infrared sources with 6C sources were used to study the infrared/radio correlation (Cox et al. 1988 MNRAS **235**,1227), and the local radio luminosity functions of spiral and elliptical galaxies (Condon 1989 ApJ **338**,13) were obtained from radio indentifications (Condon & Broderick 1988 AJ **96**,30) of UGC galaxies in the NRAO 1400MHz sky maps covering $-5° < \delta < +82°$. Similarly, the MIT-Greenbank (MG) 4.85GHz surveys made with the 91m telescope were designed to discover rare gravitationally lensed QSOs. The MG II survey (Langston et al. 1990 ApJ Suppl **72**,621) covers $4^h < \alpha < 21^h$, $+17° < \delta < +39°$ and contains 6182 sources.

The Cambridge 81.5MHz interplanetary scintillation (IS) survey catalogs 1789 source components smaller than θ~2" in the declination range $-10° < \delta < +83°$ (Purvi et al. 1987 MNRAS **229**,589). The final installment of 109 sources in the Ooty 327MHz occultation list of about 1100 sources with accurate positions in the $-19° < \delta < +19°$ band was presented by Akujor et al. (1989 A&A Suppl. **80**,215).

Smaller surveys have been made of selected areas, often with higher sensitivity. The Miyun aperture synthesis telescope mapped the $10° \times 10°$ area centered on DA 240 with $3'.8 \times 3'.8 \mathrm{cosec}\delta$ resolution at 232MHz and detected 120 background sources stronger than 0.22Jy (Qian and Wei 1988 Chinese A&A **12**,87). The Molonglo synthesis telescope (MOST) mapped a total of 20deg^2 with 43"x43"cosecδ resolution at 843MHz. The resulting counts of sources stronger than S~1mJy cover the widest logarithmic flux-density range from a single instrument (Subrahmanva & Mills 1987 IAU Symp.124,p569). Coleman & Saslaw (1990 ApJ **353**,354) used a 1411MHz VLA survey containing 297 sources stronger than 5mJy in a $4° \times 4°$ region at $\alpha=15^h$, $\delta=+11°$ to show that radio sources are Poisson distributed on scales $\gtrsim$50Mpc. The GB3 1400MHz survey detected 502 sources stronger than S=112mJy in a 0.1sr region near $\delta=73°$ (Rys and Machalski 1987 Acta Astron. **37**,163). The 100m telescope surveyed a $10° \times 6°$ area around the north ecliptic pole ($\alpha=18^h$, $\delta=66°.5$) and detected 469 sources at 2.7GHz (Loiseau et al. 1988 A&A Suppl. **75**,67) in anticipation of the ROSAT X-ray survey.

Extremely deep surveys covering small areas of sky have been made to determine the nature of the faint-source population. VLA observations and optical identifications (Benn et al. 1988 MNRAS **230**,1) plus JHK photometry (Benn et al. 1988 MNRAS **235**,465) of sources in the 408MHz 5C12 survey neat the north galactic pole were obtained. The extensive Leiden-Berkeley Deep Survey (LBDS) has been continued with a WSRT survey at 1415MHz to 0.45mJy of two fields in Hercules (Oort & van Langevelde 1987 A&A Suppl **71**,25) and deep surveys in the Lynx area reaching 0.1mJy at 1415MHz (Oort 1987 A&A Suppl **71**,221) and 4.75mJy at 327MHz (Oort et al. 1988 A&A Suppl **73**,103). The WSRT 1.4GHz amalgamated source counts above 0.1mJy now have quite low statistical uncertainties and define the inflection in the normalized source counts below S~1mJy accurately (Katgert et al. 1988 A&A

195,21). The median angular size of sources selected at 1.4GHz decreases with flux density to <1" below S=1mJy (Oort et al. 1987 A&A **179**,41; Oort 1988 A&A **193**,5). At 5GHz fluctuations in the cosmic microwave background may be comparable with confusion, and extremely sensitive VLA surveys have been made to detect faint sources and set upper limits to the background fluctions on ≤1' scales (Fomalont et al. 1988 AJ **96**,1187). Direct counts of sources as faint as S=25μJy from maps with 5mJy rms noise have been reported (Kellermann & Fomalont 1988 Proc. IAU Symp.**130**, p.379).

Structure and Spectra of Sources - At 102 and 327 MHz the interplanetary scintillation technique was employed by Vetukhnovskaja (1987 Sov.Astr.Let.**13**,154), Artyukh (1987 Sov.Astr.Let. **13**,108) and Banhatti and Ananthakrishnan (1989 MNRAS **240**,117) to study the spectra of compact source components and to extend the known correlation between total flux and scintillating fraction to smaller flux densities. At 327 MHz Akujor (1989 A&A Suppl **80**,215) observed 106 weak sources and found no difference between the high and low frequency spectra of these sources. The RATAN 600 telescope was used to measure various samples at 3.9 and 7.7 GHz (Aliakbero et al. 1987 Astrofiz.Issled.Izv.SAO **24**,178; Malumyan 1987 Sov.Astr.Let.**13**,156; Pariiski et al. 1987 Sov.Astr.Let.**13**,350; Konnikova and Sidorenkov 1988 A.Zh. **65**,263). In a deep VLA 5 GHz survey Donnelly et al. (1987 ApJ **321**,94) established the spectral index distribution of sources down to the 0.1 mJy level. Kulkarni et al. (1990 A&A Suppl **82**,41) measured 770 B3 sources at 1.4 and 4.75 GHz in order to improve the relation between flux density and spectral index. Twenty-four optically weak, compact steep spectrum (CSS) sources were measured over a wide frequency range (radio and optical) by Cotton et al. (1989 ApJ **338**,37), who find agreement with the presence of bulk relativistic motion in these sources. Machalski and Inoue (1990 MNRAS **243**,209) observed 112 GB sources at 10 and 40 GHz and find that 5-8% are CSS sources; others with 'humped' spectra are probably very compact ones. Edelson (1987 AJ **94**,1150) observed 176 bright, compact sources from the VLA calibrator list at 20 and 110 GHz. The lower frequency was used at two epochs and variability was found only for the flat spectrum sources. Steppe et al. (1988 AASuppl **75**,317) gave a catalog of 90 and 230 GHz fluxes for 294 sources; variability curves are given for 47 sources. Maslowski and Kellermann (1988 AJ **95**,1659) presented an atlas of high resolution 5 GHz maps for 101 faint sources from various surveys in which source parameters and optical identifications are given. The VLA was used at 1.5 GHz to map 1103 B3 sources (Vigotti et al. 1989 AJ **98**,419); identifications are proposed for 354. The percent identification, LAS and spectral index is studied as function of flux density. An intrinsic radio-optical displacement is inferred for steep spectrum sources and the metric size decreases with redshift. Benn et al. (1988 MNRAS **230**,1) mapped 274 5C12 sources with the VLA and optically identified 30% of them. The median spectral index is significantly flatter for radio galaxies than for the whole 5C12 sample, implying the unidentified sources have higher radio luminosity. Riley (1989 MNRAS **238**,1055) mapped 44 strong sources from the 6C survey and increased the identification fraction from 25 to 50%; effects of confusion and resolution on the membership in the 3CR sample are small. MERLIN and VLA were used to map 55 CSS sources (Spencer et al. 1989 MNRAS **240**,657). Component sizes <0.1" were found even for sources with steep high frequency spectra. QSO's generally show complex structure, while galaxies are mostly of simple double type. Further studies of the LBDS sample were published by Oort (1987 A&A **179**,41; 1988 A&A **193**,5). The median angular size decreases with total flux between 1 and 10 mJy and is larger for red or elliptical than for the blue galaxies.

Galaxies - Large samples of spiral galaxies were observed by Condon (1987 ApJ Suppl **65**,485+543) and Gioia and Fabbiano (1987 ApJ Suppl **63**,771). Vila et al. (1990 MNRAS **242**,379) mapped 28 Sbc galaxies with strong central radio sources at arcsec resolution and found the radio emission mostly dominated by the nucleus, with the total energies and magnetic fields similar to that of Seyfert nuclei. In a decametric survey of 133 mostly late type spiral galaxies, Israel and Mahoney (1990

ApJ **352**,30) detected half. Most of their integrated spectra show a low-frequency turnover, which increases with the optical axial ratio of the galaxies (being strongest for edge-ons). This is interpreted as due to free-free-absorption in galaxy disks, and a general lack of non-thermal haloes in disk-dominated spirals is inferred. Braun (1990 ApJ Suppl **72**,761) lists 534 point sources in M31, half of which are identifiable with Hα nebulae, SNR's, compact X-ray sources of M31 or with other radio sources. Based on MOST maps of 37 bright galaxies Harnett (1987 MNRAS **227**,887) compared the radial behavior of the radio emission and blue light. Fabbian et al. (1989 ApJ **347**,127) observed 84 E/S0 galaxies down to the lowest radio luminosities yet reported. For the luminous ones the radio emission is well contained within 1 kpc from the core, and correlations with optical and X-ray data are discussed. Some 114 nearby E/S0 galaxies were searched for weak sources with the VLA by Sadler et al. (1989 MNRAS **240**,591) and 42% of the objects were detected. It is concluded that most bright early-type galaxies have low-luminosity non-thermal radio sources. Giovannini et al. (1988 A&A **199**,73) searched 39 sources from the B3 and 3C surveys for radio nuclei in E-galaxies. 24 of them were detected and merged with a large sample drawn from literature. Correlations between core and total power, optical magnitude and redshift are discussed. Ekers et al. (1989 MNRAS **236**,737) presented flux data from 30 MHz through 15 GHz for a sample of 91 southern radio galaxies. Turner et al. (1988 PASP **100**,452) cataloged 2380 MHz fluxes for 120 Virgo cluster galaxies and observed 48 of them at sub-arcsec resolution. In most cases disk emission dominates over that of the nucleus, and flux concentration is greater in E/S0 galaxies than in spirals.

There is a tight correlation between radio and IR fluxes of galaxies. This holds from 151 MHz (Cox et al. 1988 MNRAS **235**,1227) to 5 GHz (Wunderlich et al. 1987 A&A Suppl **69**,487), the latter over a flux density range of 5 orders of magnitude. The relation even holds spatially for individual galaxies (Beck & Golla 1988 A&A **191**,L9). There is, however, some disagreement about the slope of the correlation. From 74 strong 6C sources/strong FIR emitters, most of them spirals, Cox et al. found that the FIR/radio flux ratio decreases with IR flux. A SNR origin of the correlation can be excluded. Based on a larger data set from literature, Devereux and Eales (1989 ApJ **340**,708) also find a slope different from unity. However, both Garwood et al. (1987 ApJ **322**,88) and Unger et al. (1989 MNRAS **236**,425) present 1.4 GHz observations of 30 to 156 IRAS galaxies and find the FIR/radio ratio independent of IR flux, of the Hubble type, and of the presence of a nuclear bar. Based on VLA observations of high FIR luminosity galaxies, Eales et al. (1988 ApJ **328**,161) find the radio emission to be optically thin and caused by star formation rather than by an AGN. Hacking et al. (1989 ApJ **339**,12) used VLA maps of Very Deep IRAS Survey sources to argue that the 1.5 GHz luminosity function (LF) for spirals evolves at less than (1+z) relative to the LF at 60 mJy.

<u>Magnetic Fields in Galaxies</u> - In 1989 the IAU Symposium **140** (ed. R. Beck et al., Kluwer, Dordrecht) on interstellar and intergalactic magnetic fields was held in Heidelberg. The mapping of polarized radio synchrotron emission at a number of frequencies allow the derivation of the orientation of the magnetic fields free of Faraday rotation effects. It was usual to combine the low frequency information from the VLA with higher frequency maps from Effelsberg for a particular galaxy. Generally magnetic fields follow the spiral arms. All the northern nearby galaxies (e.g. M31, M33, M51. M81, IC342 etc.) have been investigated in the past three years. Also southern galaxies (LMC, SMC, NGC4945, etc.) have been mapped at several frequencies in polarization using the Parkes telescope. In general the multimode dynamo theory has been used to interpret the morphology of the magnetic fields. Recent results on the edge-on galaxies NGC4631 and NGC891 have shown that uniform magnetic fields exist also in halos of galaxies. The derivation of the magnetic field strength depends on the assumption of equipartition between cosmic ray energy and the magnetic field energy. From such arguments values of the average field of $50\mu G > B > 3\mu G$ have been derived for various galaxies.

In our Galaxy the magnetic field was known to be along the spiral arms from radio and optical polarization observations. Recently it has been shown that in the galactic centre area the magnetic fields are poloidal (i.e. in the z-direction). In other galaxies (e.g. M82, M104, NGC1808 etc.) poloidal magnetic fields have also been observed. A scenario has been developed which suggests that poloidal fields in a nucleus are caused by the dynamo amplification of a seed field due to a current flowing in a rotating molecular ring seen in the nuclear area.

Molecules in Extragalactic Sources - The use of large mm-wave telecopes with sensitive SIS receivers lead to the detection of CH_3OH, HNC, C_2H, CN, HC_3N, HNCO, N_2H^+, CH_3CCH, and SiO (Henkel et al. 1987 A&A **188**,L1; Henkel et al. 1988 A&A **201**,L23; Rieu et al. 1989 A&A **220**,57; Mauersberger & Henkel 1989 IAU Cir 4889; Mauerberger et al. 90 IAU Cir 4906; Mauersberger & Henkel 1990 IAU Cir 5021), increasing the number of observed molecular species from 11 to 20. In the nearest galaxy, the LMC, a complete CO survey has been obtained (Cohen et al. 1988 ApJ **331**,L95). The most distant galaxies detected in CO λ2.6mm and OH λ18cm lines are Mrk 1014 and IRAS 1201+1941 with cz=48900 and 50400 kms^{-1}, respectively (Sanders et al. 1988 ApJ **335**,L1; Martin et al. 1988 A&A **201**,L13).

The relation between infrared and CO luminosities has been verified for a large variety of galaxies, including dwarf irregulars, starburst, Seyfert galaxies and lenticulars (e.g. Tacconi and Young 1987 ApJ 322 681; Heckman et al. 1989 ApJ **342**, 735; Wiklind and Henkel 89 A&A **225**,1). The large scatter in the L_{IR}/L_{CO} ratios can be reduced by accounting for the dust temperature. Good linear correlations are also found between $S_{100\mu m}$, CO(1-0), CS(2-1), and CII(λ158μm) for a sample of bright infrared galaxies, indicating that $S_{100\mu m}$ and the lines all trace the star forming rate (Sage et al. 1990 ApJ **351**,422).

Typical CO J=2-1/J=1-0 line temperature ratios are 0.5-1.0, indicating the presence of optically thick cool gas. This also holds for starburst galaxies (e.g. Casoli et al. 1989 A&A **192**,L17; Verter et al. 1989 A&A **225**,27), even though other spectral lines (e.g. CO(3-2) and CS(5-4); Ho et al. 1987 ApJ **322**,L67; Ho et al. 1990 ApJ **355**,L19; Turner et al. 1990 ApJ **351**,418; Mauersberger & Henkel 1989 A&A **223**,79) indicate the presence of warm molecular gas.

Arm-interarm CO intensity contrast are now well established for i.e. M51, IC342, and M83. Values range from 1.5:1 to >3:1, depending on angular resolution and source. Tangential velocity gradients as predicted by the density wave theory are seen. In M51, the expected offset between ridges of HI and radio continuum as well as between Hα emission and the CO arms is also observed (e.g. Rydbeck et al. 1987 NASA Conf.Pub. 2466,315; Lo et al. & Vogel et al. 1988 *Symp.on Mol. Clouds in the Milky Way and Ext. Gal.*, ed. Dickman, Snell, Young, Springer Verlag, Heidelberg, p.437,439).

The galaxies with largest infrared luminosities, most believed to be the result of mergers, emit the bulk of their IR and CO radiation from the nuclear region (e.g. Scoville et al. 1989 ApJ **345**, L25). Pairs of galaxies with larger separation can exhibit more complex distributions (e.g. Sargent et al. 1987 ApJ **312**,L35; Combes et al. 1988 A&A **203**,L9). The nuclei of some nearby bright IRAS galaxies, which are sufficiently resolved to show some detail, exhibit bars or rings when observed in CO or other species. Typical examples for bar-like structures are NGC253 (Canzian et al. 1988 ApJ **333**,157), IC342 (e.g. Ishizuki et al. 1990 Nature **344**,224), Maffei2 (Ishiguro et al. 1989 ApJ **344**,763), and NGC6946 (Ishizuki et al. 1990 ApJ **355**,436). These may allow dense gas to stream inwards. NGC1068 (Myers & Scoville 1987 ApJ **317**,L39), M82 (e.g. Smith et al. 1990 MNRAS **243**,97) and NGC4945 (Whiteoak et al. 1989 A&A **231**,25) exhibit ringlike structures, perhaps a consequence of a nuclear wind.

Stimulated by the IRAS survey, a large number of lenticulars has now been detected in CO (see Sage and Wrobel 1989 ApJ **344**,204; Thronson et al. 1989 ApJ 344,747; Wiklind and Henkel 1989 A&A **225**,1). While the molecular gas mass is lower than in spirals by at least an order of magnitude, the star forming efficiency (SFE) is similar. This SFE, obtained in grand-design and flocculent spirals (Stark et al. 1987 ApJ **322**,64) and lenticulars indicates that density waves do not significantly influence overall star forming rates. A few ellipticals have also been observed in CO (e.g. CenA, PerA; Phillips et al. 1987 ApJ **322**,L73; Israel et al. 1989 A&A **227**,342; Lazareff et al. 1989 ApJ **336**,L13; Mirabel et al. 1989 ApJ **340**,L9). The complete CO map of the LMC (Cohen et al. 1988 ApJ **331**,L95) demonstrates that giant molecular complexes can also form in irregulars. The $I_{CO}/N(H_2)$ conversion ratio appears to be a factor of six over the galactic value, probably a consequence of low metallicity.

The number of "megamasers" has doubled due to sensitive surveys of IRAS galaxies (Martin et al. 1988 A&A **201**,L13; Kazes et al. 1988 and 1989, IAU Cir **4629+4856**; Bottinelli et al. 1990 IAU Cir **4928+4977**). Southern hemisphere surveys are now underway (Norris et al. 1989 MNRAS **237**,673); these have yielded IRAS 20100-4156 (Staveley-Smith et al. 1990 Nature **337**,625), the most powerful cosmic maser known. It has a redshift of z = 0.13, but is so powerful it would be detectable at a redshift exceeding 0.5. These masers are believed to be unsaturated, amplifying the nuclear radio continuum. Excitation is mainly due to infrared radiation. The emission arises within a few 100pc from the nucleus (Henkel&Wilson 1990 A&A **229**,431; Burdyuzka&Vikulov 1990 MNRAS **244**,80). Observations of the OH 18 cm satellite lines (Baan & Haschick 1987, ApJ **318**, 139) and the 6 cm lines, which are seen in absorption (Henkel et al. 1987 A&A **185**,14), provide important evidence on the OH excitation. Wide linewings seen in some sources (e.g. Staveley-Smith et al. 1987 MNRAS **226**,689; Baan et al. 1989 ApJ **346**,680). A significant part of the λ18 and 6cm emission might arise from distances of 10pc. Megamasers may be a sign of a heavily obscured active nucleus (Sanders et al 1988 ApJ **325**,74). The rare kilomasers, showing narrow emission within a broad absorption feature are a very heterogenous family of sources (see Mirabel et al 1990 ApJ **346**,680; Baan 1989 ApJ **338**,804; Burdyuzha&Vikulov 1990 MNRAS 244,86; Henkel&Wilson A&A **229**,431). A second 6cm formaldehyde maser has been found in NGC253 (Baan et al. 1989 ApJ **353**,132).

VLBI observations of the prototype megamaser Arp 220 show sizes <4 pc (Diamond et al. 1989 ApJ **340**,L49). No new superluminous H_2O masers have been detected, but the first nuclear H_2O masers with "normal" luminosity have been observed, in NGC253 and M51 (Ho et al. 1987 ApJ **320**,663; see also Nakai&Kasuya 1988 PAS Japan **40**,139; Huchtmeier et al. 1988 A&A **200**,26). Intercontinental VLBI results from the most luminous H_2O maser, in NGC3079, show that the separation of individual components is 7 10^{16}cm; the components are spatially unresolved (<1.5 10^{16}cm; Haschick et al. 1990 ApJ **356**,149).

VLBI observations of two masers show that these are extremely compact, with overall extents of 0.01 pc or less (Claussen et al. 1988 IAU Symp No.**129**,p.231; Haschick et al. 1988 ibid,p.233). One of the sources, NGC 4258, shows periodic variations (Haschick & Baan 1990 ApJ **355**,L23). The future use of extragalactic H_2O masers for determining distances to nearby galaxies has been reviewed by Reid et al. (1988 IAU Symp No.**129**,p.169).

Extragalactic Atomic Hydrogen - A general review is "Extragalactic Neutral Hydrogen" (Giovanelli and Haynes, 1988 in *Galactic and Extragalactic Radio Astronomy*, ed. Verschuur and Kellermann, Springer, Heidelberg, p.522). Data for >8000 galaxies are in (Huchtmeier and Richter 1989: *A General Catalog of HI Observations of Galaxies*, Springer, New York). Several publications may be found in the IAU Symp. No.**130** *Large Scale Structure of the Universe* and in the Astrophys. Space Sci.Lib. vol.151 *Large Scale Structure and Motions in the Universe*. A set of strong "standard" galaxies have been observed with different telescopes and reduced with the same software in order to check the accuracy of observed velocities and fluxes (Tifft and Cocke 1988 ApJ Suppl **67**,1). Large surveys of cluster of galaxies have been performed to derive global properties of those galaxies and to established the HI-deficiency in the central area of the Virgo cluster (van Driel et al. 1988 A&A **205**,47; Warmels 1988 A&A Suppl **72**,19 and **57** and **73**,453 ; Phillipps 1988 A&A **194**,77; Huchtmeier and Richter 1989 A&A **210**,1; Hoffman et al. 1989 ApJ **339**,812; ApJ Suppl **69**,65; 1990 ApJ Suppl **71**,701; Schneider et al. 1990 ApJ Suppl **72**,245).

Other clusters studied for similar reasons and in view of their importance for the large scale structure were Hydra-Centaurus (Fouque 1987 A&A **185**, 94; Ferguson et al. 1987 BAAS **19**,686), Coma (Gavazzi 1987 ApJ **320**,96 and 1989 ApJ **346**,59), Perseus-Pisces (Giovanelli and Haynes 1989 AJ **97**,633; Hauschildt 1987 A&A **184**,43), and Hercules (Freudling et al. 1988 AJ **96**,1291).

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The regions devoid of galaxies have been looked at; a small spiral galaxy has been detected (Henning and Kerr 1989 ApJ **347**,L1). The zone of avoidance (within 15 deg of the galactic equator) masks about 25% of the sky . Since the 21cm emission of galaxies is not affected by the optical obscuration, several surveys to search for extensions of filaments and superclusters observed outside this zone (Hauschildt 1987 A&A **184**,43; Kerr and Henning 1987 ApJ **320**,L99; Kraan-Korteweg 1989 Rev.Modern Astronomy **2**, p.31, Springer, Heidelberg). Larger surveys of limited regions of the sky or certain morphological types (Becker et al. 1988 A&A **203**,21; Davies et al. 1988 MNRAS **231**,832 and 1989 MNRAS **236**,171; Huchtmeier & Richter 1988 A&A **203**,237; Staveley-Smith and Davies 1988 ApJ **324**,L59 and 1989 MNRAS **236**,171; Puche and Carignan 1988 AJ **95**,1025). Luminous IRAS galaxies are also the objects of many surveys (Garwood et al. 1987 ApJ **322**,88; Mirabel & Saunders 1988 ApJ **335**,104 and 1989 ApJ **340**,L53 and L133), as are early-type and lenticular galaxies (Burstein et al. 1987 AJ **94**,883; van Driel et al. 1988 A&A **191**,201 and A&A **199**,41; 1989 A&A **218**,49 and A&A **225**,317). Intergalactic hydrogen clouds, sought for over a decade, have been found (Steidel and Sargent 1987 ApJ **318**,L11; Djorgovski 1990 AJ **99**,37; Impey et al. 1990 ApJ **351**,L33; Giovanelli and Haynes 1989 ApJ **346**,L5).

There has been a growing interest in gas content and star formation in irregular galaxies (Skillman et al. 1987 A&A **185**,61 and 1988 A&A **198**,34; Carignan et al. 1988 AJ **95**,37 and ApJ **347**,760 and AJ **99**,178; Shostak and Skillman 1989 A&A **214**,33; Lake et al. 1990 AJ **99**,547).

Our knowledge of elliptical galaxies changed with respect to their interstellar matter content (Bregman et al. 1987 ApJ **330**,L93; Kim et al. 1988 ApJ **330**,684; Schweizer et al. 1989 ApJ **338**,770; van Gorkom et al. 1989 AJ **97**,708; Wals et al. 1990 ApJ **352**,457; further contributions are to be found in IAU-Symp. No.**127** *Structure and Evolution of Elliptical Galaxies* ed. Zeuuw, Kluwer, Dordrecht and in the NATO ASI Series *Cooling Flows in Clusters and Galaxies*, ed. Fabian, Kluwer, Dordrecht).

21cm absorption quasars has been searched for by Krishan (1988 MNRAS **231**,353); Brown et al. 1988 ApJ **329**,138). An absorption line survey of M31 was carried out by Dickey and Brinks (1988 MNRAS **233**,781; more contributions may be found in the Sp.Tel.Sci.Inst.Symp.Ser. **2** *Workshop on QSO Absorption Lines*). A number of individual galaxies have been studied in detail: M33 (Cortelli et al. 1989 AJ **97**,390; Deul et al. 1990 A&A **229**,362); Observations of high-velocity-clouds in M101 have been confirmed (van der Hulst and Sancisi 1988 AJ **95**,1354). A search for HI high velocity clouds in nearby edge-on spiral galaxies followed (Wakker et al. 1989 A&A **226**,51). ARO193 (Appleton et al. 1987 Nature **330**,140), NGC5635 (Saglia and Sancisi 1988 A&A **203**,28), NGC5963 (Bosma et al. 1988 A&A **198**,100). With the possible exception of galaxies in central areas of large clusters, flat rotation curves are typical (Guhathakurta et al. 1988 AJ **96**,853; Rubin et al. 1989 AJ **98**,1246; Begeman 1989 A&A **223**,47).

<u>Seyferts and AGN</u> - Ulvestad and Wilson (1989 ApJ **343**,659) obtained maps of 27 nearby Seyferts and thus completed mapping of the 57 closest Seyferts known to 1983. Evidence for Sy2 being more luminous and larger radio sources than Sy1 was found to be marginal, contrasting with a study of literature data by Giurici et al. (1990 ApJ Suppl **72**,551), who question the idea that Sy2 are simply obscured Sy1's. Edelson et al. (1987 ApJ **321**,233) limits ν>230 GHz for 48 Seyferts from a spectroscopically selected sample.

Norris et al. (1988 MNRAS **234**,773,+51P) found Seyfert and starburst activity in maps of 14 optically faint IRAS galaxies. Members of both types of activity were found in the sample. From 1.4 GHz VLA observations of eight emission-line galaxies in the Bootes void, Burns et al. (1988 AJ **95**,668) conclude that radio and optical properties of these galaxies are remarkably similar to those of active galaxies in clusters. Chini et al. (1987 A&A **181**,237) found 5 positional coincidences between the IRAS and a VLBI survey; measurements at 245 GHz suggest that these are 'super star bursters'. Observations at ν>230 GHz of some 20 Markarian galaxies (Krügel et al. 1988 A&A **190**,47; Chini et al. 1989 A&A **216**,L5) and nuclei of 8 FIR-bright galaxies (Thronson et al. 1987 ApJ **318**,645) showed that their sub-mm continuum is almost entirely due to thermal dust emission.

Israel et al. (1988 A&A **189**,7) detected 12 of 55 Markarian/Sy galaxies at 10.7 GHz; spectral differences between Sy1 and Sy2 objects are discussed.

QSO's - Quiniento et al. (1988 A&A Suppl **76**,21) present 1.4 GHz fluxes as well as the low and high frequency spectral indices for 243 southern QSOs. Kellermann et al (1989 AJ **98**,1195) mapped all 114 objects from the Palomar Bright Quasar Survey with the VLA at 5 GHz; there appears to be no difference in the radio properties of AGNs and QSOs. The existence of radio-loud (15-20% of the sample) and radio-quiet QSOs cannot be explained simply by the geometric or beaming effects of objects with intrinsically fixed radio-to-optical luminosity. Barvainis and Antonucci (1989 ApJ Suppl **70**,257) measured 17 radio-quiet QSOs and luminous Sy1 from the IRAS Point Source Catalog between 1.5 and 230 GHz; for ν>40 GHz only upper limits were reported. The spectra show a large variety and include a high frequency excess for ν>15 GHz in many sources. O'Dea et al. (1988 AJ **96**,435) observed 16 core-dominated QSO's and AGN's from 5 to 23 GHz.

Maps covering several clusters of galaxies have been made: the Cancer cluster at 1.4GHz with the VLA D-array (Dickey & Salpeter 1987 ApJ **317**,102), Abell 262 at 327MHz with WSRT (Righetti et al. 1988 A&A Suppl.**74**,315), Abell 1314 at 408 and 1420MHz with the Penticton synthesis telescope (Vallée & Roger 1989 A&A Suppl **77**,31), the Coma cluster at 326MHz and 1465MHz (Venturi et al. 1990 AJ **99**,1381), and an area without nearby rich galaxy clusters (Condon et al. 1990 AJ **99**,1071).

Clusters of Galaxies - The proceedings of the NRAO Green Bank Workshop 16 on *Radio Continuum Processes in Clusters of Galaxies* 1987, (eds. Uson and O'Dea), gave an overview over all aspects of radio emission from clusters. Strong attention was paid again to Abell clusters, above all the Coma cluster. Kim (1988 PhD Univ.Toronto) lists 780 sources found at various frequencies out to 3 degs. from the Coma centre. From the Coma data, the sources closer to the center to have steeper spectra. Further studies of the central radio halo Coma C were presented by Henning (1989 AJ **97**,1561) and Schlickeiser et al. (1987 A&A **182**,21). DelCastillo et al. (1988 AJ **95**,1340) gave a list of 1.4 GHz fluxes and radio spectra for 148 CGCG galaxies in the Coma supercluster region. Slee et al. (1989 Austral J Phys **42**,633) listed 940 sources from a VLA survey of 58 Abell cluster fields. Statistical criteria for cluster membership of sources, and correlations of radio with other cluster properties were derived. In continuation of the Effelsberg Abell cluster survey, Andernach et al. (1988 A&A Suppl **73**,265; 199 A&A Suppl **82**,279) found a further 260 sources in 46 cluster fields and gave radio spectra and optical identifications. Statistical evidence for a 'relic' source population (steep spectrum, optically unidentified) associated with the clusters was noted. Righetti et al. (1988 A&A Suppl **73**,173 and **74**,315) present a 327 MHz WSRT survey of A262, and only 9 of 309 detected sources were identified with cluster galaxies. Vallée and Roger (1989 A&A Suppl **77**,31) find a similar result for A1314 based on 408/1420 MHz DRAO surveys. Together with Righetti et al. (l.c.) they find no difference in the cluster and field source counts, and no evidence for individual 'relic' sources. For a complete sample of nearby Abell clusters Zhao et al. (1989 AJ **98**,64) present a catalogue of sources definitely associated with cluster galaxies. Moffet and Birkinshaw (1989 AJ **98**,1148) made a VLA survey of three very rich clusters to find accurate corrections to their microwave decrement. Decametric spectra for 12 cluster sources were obtained by Subramanian and Sastry (1989 Bull AS India **16**,183). Harris et al. (ApJ **325**,610) present a study of five steep spectrum sources from the Clark Lake survey. Three out of five sources were found to be embedded in a cluster atmosphere, with sufficient thermal pressure (derived from X-ray images) to confine the radio sources.

Broten et al. (1988 Ap.Space Sci.**141**,103) gave an all-sky catalog of unambiguous rotation measures for 674 galaxies and QSOs. Polarization measurements were performed towards limited regions of sky in order to unravel the magnetic field structure of either our galaxy (Vallée et al. 1988 ApJ **331**,321; A&A **196**,255; MacLeod et al. 1988 A&A Suppl **74**,63; Bignell et al. 1988 ApJ Suppl **67**,279) or that of the Virgo and the Great Attractor superclusters (Vallee et al. 1990 AJ **99**,459;

Vallee et al. 1989 Ap.Space Sci.**152**,9). More sources with intrinsically very large RM were found (Kato et al. 1987 Nature **329**,223; Aizu et al. 1990 IAU Symp **140**). Hennessy et al. (1989 ApJ **347**,144) found no evidence that the distribution of accurate rotation measures (observed with the VLA) differs for sources seen behind Abell clusters and sources not behind Abell clusters.

Source Variability - From daily monitoring of 33 compact sources from 1979-85, Fiedler et al. (1987 ApJ Suppl **65**,319) have obtained statistical unequaled results on source variability. Variability time scales range up to one year for BLLac's and to 1.6 years for QSOs. Heeschen et al. (1987 AJ **94**,1493) have studied the short-term variability of 31 compact sources on time scales of hours and days. Variability was found only for the flat spectrum sources and ISM scintillation is the most likely cause. Intrinsic rapid variability is not present (Quirrenbach et al. 1989, Nature **337**,442). Based on 3000 observations of 48 sources at 12, 22 and 37 GHz from 1980-85 (Salonen et al. 1987 A&A Suppl **70**,409), Valtaoja et al. (1988 A&A **203**,1) were able to separate, for the first time, the quiescent component from some flare spectra. Even the most compact cores were found to be transparent >200 GHz; from time-dependent spectra for 17 flares a universal emission spectral index of 0.2 for freshly injected particles was inferred.

Slee and Siegman (1988 MNRAS **235**,1313) monitored 412 sources at 80/160 MHz and found 47% to be variable. Some Statistical conclusions are drawn. Forkert and Altschuler (1987 A&A Suppl **70**,77) surveyed a narrow declination strip at 2.7 and 4.75 GHz. By comparison with observations at an earlier epoch, ten markedly variable sources were found. Giacani and Colomb (1988 A&A Suppl **76**,15) monitored southern BLLac's weekly from Apr85 to Feb87 and find 50% with S(1.4)>1Jy to be variable. Vetukhnovskaja (1989 A.Zh. **66**,561) observed low-frequency variables and found their spectra to remain flat down to 102 MHz. Haddock et al. (1987 AJ **93**,1356) monitored 16 bright sources at 24 GHz over 17 months. Stronger variability is generally found than at lower frequencies, as confirmed by Botti and Abraham (1988 AJ **96**,465) in a study of the long-term variability of 3C273. Morabito et al. (1988 AJ **95**,1037) reported a radio flare in the M87 nucleus. This is interpreted within the theory of expanding synchrotron components or relativistic shocks propagating down a preexisting jet. Using the latter model, Hughes et al. (1989, ApJ **341**,68) also could explain the variability of the polarization vector. Variability at low frequencies (decimeter wavelength) on similar timescales is at least in part attributed to refractive scattering in the interstellar medium (RISS). The same effect has been made responsible for the small and erratic intensity variations at high frequencies on timescales of days ("flickering") found by Heeschen et al. (1987 AJ **94**,1493). Small scale inhomogenities of the ISM have been observed as unusual occultation effects by Fiedler et al. (1987 Nature **326**,675). Angular broadening of the milliarc-sec structure of compact radio sources behind SNR's by RISS has been demonstrated by Spangler et al. (1987 ApJ **322**,909). However, recently intensity variations on time scales as short as 10 to 15 hours with relative amplitudes of up to 30 percent have been discovered. The degree of variability to first order is independent from the observing frequency (Quirrenbach et al. 1989 Nature **337**,442), and may be related to enhanced fast optical variability. Fluctuations of polarization in 0917+624 are anticorrelated with the intensity variations. These observations have led to the conclusion that this type of variability must be intrinsic to the source (Witzel et al. 1990 in *Parsec Scale Radio Jets*, PSRJ, Camb.U.P. p.206). The model of Camenzind (1990 Rev.Mod.Astron.**3**, Springer Verlag) is able to reconcile measurements with the upper limit for the brightness temperature imposed by the inverse-Compton effect.

VLBI and Compact Sources - The study of active galactic nuclei (AGN, e.g. quasars, BL, Lacs, cores of Seyfert galaxies) and their jets has received considerable impetus in recent years. In complete flux density limited samples of flat spectrum radio sources apparent superluminal motion of features and knots within the inner radio-jets, high brightness temperatures going with a lack of observed inverse-Compton X-radiation, is a common phenomenon (Witzel et al. 1988 A&A

206,245; Pearson&Readhead 1988 ApJ **328**,114). "Superluminal brightening" has been observed in 3C454.3 (Pauliny-Toth et al. 1987 Nature **328**,778). These findings consistent with an interpretation on the basis of the relativistic beaming model. Samples of quasars selected by their extended emission from the lobes at low radio frequencies, which therefore should not show orientation bias, have been defined. First results revealed superluminal motion near the nucleus in 3C179 (Porcas 1987 in *Superluminal Radio Sources* hereafter "*SRS*", Camb.U.Press, p.12), 3C263 (Zensus et al. 1987 Nature **325**,36) and in 3C245 (Hough & Readhead 1987 in *SRS*, p.114), although at speeds significantly lower than in core dominated sources. Barthel (1989 ApJ **336**,606) has suggested that large radio galaxies of the FR2 class form the parent population of quasars, the latter being those oriented at an angle of less than 45° to the line of sight. Yet the deprojected size of some of the largest known superluminals appears quite large (e.g. 4C34.47: Barthel et al. 1989 ApJ **336**,601; 1928+73: Johnston et al. 1987 ApJ **246**,L85; Simon et al. 1987 SRS,p.155).

In order to first observations had been made with the TDRSS-satellite (Levy et al. 1989 ApJ **336**,1098). 24 sources were detected on baselines of up to 2.15 earth diameters, giving ~600μas resolution at 2.3GHz (Linfield et al. 1989 ApJ **336**,1105). To directly image the central engines of AGN with even higher angular resolution from ground, VLBI at mm-wavelength is required. First images of bright AGN's have been obtained at 7mm (3C84, 90μarcseconds resolution: Bartel et al. 1988 Nature **334**,131; Ohawan et al. 1990 ApJ Let **360**,L43) and 3mm (3C273, 50 μas res.; Baath et al. 1990 in *Frontiers of VLBI*, Univ.Academic Press, Tokyo). Whereas 3mm-VLBI still suffers from comparably low sensitivity, the 7mm-VLBI array now allows imaging of sources other than merely the exceptionally bright ones. 7mm-VLBI observations of 3C273 shortly after a major flux density outburst in the IR/optical-regime allowed monitoring of the ejection of plasma into the relativistic jet (Krichbaum 1990 in *Parsec Scale Radio Jets*, (ed. Zensus & Pearson, Camb.U.Press, hereafter "*PSRJ*"). VLBI observations of 3C84, revealed a subluminally expanding amorphous jet structure emanating from the nucleus. The expansion could be attributed to a large intensity outburst in the early 60's (Backer et al. 1987 ApJ **322**,74). 13mm VLBI-observations resulted in the detection of features moving with velocities different from each other (Marr et al. 1989 ApJ **337**,671). 3 epoch VLBI-observations at 7mm resolved the core-region of 3C84 into multiple compact components, probably aligned along a jet (Krichbaum, 1990 PSRJ). This structure is also visible within first 3mm-VLBI maps (Wright et al. 1988 ApJ **329**,L61). In combination with VLBI-data obtained from lower frequencies the 7mm-VLBI maps revealed for all sources imaged so far (3C273 (Krichbaum 1990 PSRJ); 3C345 (Zensus 1990, Krichbaum 1990); 3C84 (Bartel et al. 1988, Krichbaum & Witzel 1990 in *Frontiers of VLBI*) and 1803+78 (Krichbaum & Witzel 1990)) evidence that the jets of these sources are strongly bent in the proximity of their nuclei.

At centimeter wavelengths, the milliarcsecond-structure of the jets of the powerful radio sources 3C273 (e.g. Zensus et al. 1988 Nature **334**,410), 0836+71 (e.g. Krichbaum et al. 1990 A&A **230**,271), 3C120 (e.g. Benson et al. 1988 ApJ **334**,560; Walker et al. 1988 ApJ **335**,668) show a high degree of complexity including quasi-sinusoidal oscillations of the jet ridge lines, kinks and bends and asymmetric transverse jet-profiles. Superluminal motion not only appears close to their cores, but also at distances as large as a few hundred parsecs. VLBI monitoring of 3C345 shows, that the jet components move on curved (non-ballistic) trajectories with different apparent velocities. At least the inner jet components follow different trajectories (Zensus 1990, in *Frontiers of VLBI*), suggesting motion on a helically twisted path. Motion on curved pathes has also been observed in 3C273 (Krichbaum and Witzel in *Frontiers of VLBI*; Unwin et al. 1990 in PSRJ, Camb.U.P.). However, in this source no evidence for motion on different pathes was found. Many of the known superluminal sources show no simple (linear) velocity patterns of their jet components. Their velocities can change from component to component, moving and apparently stationary jet components coexist in some jets (e.g. 3C395: Simon et al. 1988 ApJ **326**,L5; 4C39.25: Marscher et al. 1987 ApJ **319**,L69; Marcaide et al. 1989 A&A **211**, L23; 0836+71: Krichbaum et al. 1990 A&A **230**,271). This behavior may be explained by decoupling the pattern speed from the speed of the underlying jet fluid.

High dynamic range images with arcsecond (Owen et al. 1989 ApJ **340**,698) and milliarcsecond resolution (Reid et al. 1989 ApJ **336**,112) of M87 show subtle detail in a pronounced well confined jet, including limb-brightening, transverse expansion, oscillations and subluminal motion. Despite the latter fact, indicative of a low degree of Doppler-enhancement due to a larger angle to the LOS, no counterjet is visible (dynamical range 2000:1), rising the question of intrinsic asymmetry. M87 was the first source, whose optical polarization of the jet was to be measured (Schötelbur et al. 1988 A&A **202**,L23). These measurements and the high quality CCD-images of the jet of 3C273 (Fraix-Burnet & Nieto 1988 A&A **198**,87) show (partly regularly spaced) jet-features, well coincident with those, observed with VLBI at radio frequencies.

Further insight to the physical mechanisms taking place in relativistic jets comes from VLBI-polarization observations (Gabuzda et al. 1988 in *BL Lac Objects*, Springer Verlag, Heidelberg, p.22), a technique, which only recently has been developed. It has been discovered that knots of the milliarcsec-jets are usually highly polarized whereas the self-absorbed cores are not. Thus, highly ordered magnetic fields should play an important role in the inner radio jets of AGN. OJ287 shows superluminal motion of its polarized structure (Roberts et al. 1987 ApJ **323**,536). 0735+188 probably shows strong changes of the polarization within 24 hours (Gabuzda et al. 1989 ApJ **336**,L59).

In BL Lac's, the direction of the magnetic field tends to be always perpendicular to the jet axis, in quasars parallel (Gabuzda et al. 1989 ApJ **347**,701; Wardle & Roberts 1988 in Proc. of IAU **129**, Kluwer, Dordrecht). There is evidence that BL Lac's are more compact than other sources (Witzel et al. 1988 A&A **206**,245) and that their jets expand more rapidly than in quasars, due to a larger jet opening angle (Mutel et al. 1989 ApJ **352**,81). Comparison of the apparent velocities in the jets of BL Lac-objects and quasars suggests that BL Lacs exhibit systematically slower motion than quasars (Cohen 1988 in *BL Lac Objects*; Gabuzda et al. 1989 ApJ **336**, L59). There are indications that the jet of BL Lac is inclined at a comparably large angle to the LOS.

The relativistic beaming model has received further support from the observation of a systematic asymmetry in the polarization properties of double lobed quasars in the sense that the brighter jet always points toward the lesser depolarized lobe (Garrington et al. 1988 Nature **331**,147; Laing 1988 Nature **331**,149). Radiation from the counterjets, pointing away from the observer, has to cross more depolarizing gas. In the case of 3C120, the influence of an invisible counterjet on the gas associated with the galaxy has in fact been detected by the observation of shocked OIII emission line gas (Axon et al. 1989 Nature **341**,631). Given that there is a common Lorentz factor of the jets, as is suggested by a dependence of the observed upper envelope of apparent speeds in all known superluminal sources, constraints can be derived on cosmological constants using the velocity of light as a 'standard candle' to calibrate apparent velocities (Cohen et al. 1988 ApJ **329**,1).

Additional to unifying schemes based on the relativistic beaming model, evolutionary scenarios have been developed to explain properties of sources, which seem to be intrinsically small (Fanti et al. 1989 A&A **231**,333) and therefore comparably young. Socalled CSS (Compact Steep Spectrum) sources are thought to be the precursors of the large FR2 radio galaxies (Mutel & Phillips 1988 in IAU **129**).
The importance of galaxy interactions or merging on the nuclear activity of AGN has been put forward by VLA and VLBI observations of the peculiar galaxy Arp220. They revealed a double compact radio nucleus (Norris et al. 1988 MNRAS **230**,345) emitting high luminosity ("megamaser") OH-maser radiation (Diamond et al. 1989 ApJ **340**,L49). Sub-Millimeter continuum observations of AGN led to the conclusion that the FIR/sub-mm emission of Markarian-galaxies results from a dust component (Chini et al. 1989 A&A **216**,L5). A linear correlation of luminosity/mass with dust-temperature has been found for galaxies, Makarians and quasars. For Markarian-galaxies a correlation between gas-mass and luminosity was derived (Krügel et al. 1988 A&A **190**,47).

Observations of gravitational lenses have been continued. The observed milliarcsecond structure of 0957+561 with 2 core-jet sources (Porcas et al. 1989 in *Cambridge Conf. of Gravitational Lenses*; Moran et al., Springer, Heidelberg) is likely

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to be explained via gravitational lensing. An "imaging matrix" was derived to describe the lens geometry (Gorenstein et al. 1988 ApJ **324**,42). Two sources with "Einstein-Rings", caused by a close alignment of object, lens and observer, have been detected (MG1131+0456: Hewitt et al. 1988 Nature **333**,537; MG1654+1346: Langston et al. 1989 AJ **97**,1283).

The Microwave Background Radiation - The major event to report is the successful launch and functioning of the Cosmic Background Explorer Satellite (COBE). Great interest was aroused by the reported discovery of an excess to the background radiation peaking at 800μm detected in a rocket experiment by Matsumoto et al. (1988 ApJ **329**,567). The excess represented approximately 10% of the energy in the microwave background itself and interpreted as a Compton distortion corresponded to a Comptonization parameter of y=0.019. However, the preliminary COBE spectrum (Mather et al. 1990 ApJ **354**,L37) shows no such distortion to a limit y=0.001, being extremely well fitted from 0.5mm to 5mm by a single black-body spectrum with $T=2.735\pm0.06$K. This represents one of the most significant and accurately measured items of cosmological information. Ground based determinations at lower frequencies and measurements using CN lines (see e.g. Kogut et al. 1990 ApJ **355**,102, for a compilation) have continued to improve, and fit well with the temperature determined by COBE.

Improved results on small scale polarization have come from Partridge et al. (1988 Nature **331**,146) who set limits of $\sim10^{-4}$ to $\Delta T_{pol}/T$ on scales from 18" to 160". The importance of polarization information as a diagnostic of microwave background fluctuations has been stressed by Bond & Efstathiou (1987 MNRAS **226**,655). COBE maps have been used to determine the ΔT dipole amplitude as 3.3 ± 0.2mK towards direction $(\alpha,\delta)=(11^h\!.2\pm0^h\!.2,\ -6^\circ\pm2^\circ)$ consistent with previous results. The most sensitive result for quadrupole anisotropy so far appears to be that from the RELICT I experiment: $\Delta T_{quad}/T\leq2\times10^{-5}$ (see Strukov et al. 1988, in Proc. IAU Symp. No.**130**, eds. Audouze et al., Kluwer, Dordrecht, p27). For a discussion of the different conventions used in expressing quadrupole amplitudes, see Scaramella & Vittorio (1990 ApJ **353**,372).

Some of the most promising developments on anisotropies on scales $\geq0.5^\circ$have come from experiments in Antartica (e.g. Lubin et al. 1990 in *The Cosmic Microwave Background: 25 Years Later*, eds. Mandolesi & Vittorio, Kluwer, Dordrecht, p115) or flown from balloons (e.g. Page et al. 1990 ApJ **355**,L1). The Lubin et al. results set an upper limit of around 2×10^{-5} on a scale of about 1°, the exact limit depending on the cosmological model assumed. This is an extremely important result, since 0.5° to 1° is the scale on which we expect maximum power from Cold Dark Matter (CDM) models (e.g. Bond & Efstathiou, l.c.). A further reduction in the upper limit on these scales by a factor 2-3 will start to put extreme pressure on CDM theories, which are already under pressure in the opposite dircetion for predicting toolittle/ power on large scales, as seen in the spectrum of matter density fluctuations. On slightly larger scales, it appears that the detection by Davies et al. (1987 Nature **326**,462) of fluctuations $\Delta T/T\sim4\times10^{-5}$ in an 8° beam at 10GHz, later confirmed at 5° resolution (Watson et al. 1989 in Proc. IAU Symp **130**) most probably is contaminated by Galactic emission. Further experiments at different frequencies are underway to separate out this contribution. The DMR experiment on COBE has the potential (depending on the satellite's lifetime) of getting down to the 1 or 2×10^{-5} level on a 7° scale over the whole sky, rather than in the small patches which have to be concentrated on in ground based experiments. Careful removal of foreground contamination will be needed here also however.

The OVRO measurements of Readhead et al. (1989 ApJ **346**, 566) at 20GHz, limit fluctuations to $\leq1.9\times10^{-5}$ ($\Delta T/T$) on a scale of 2' to 7'. This very sensitive result, together with the Lubin et al. and Davies et al. results on larger scales, severly constrain the range of theories of galaxy formation to cold dark matter and baryon isocurvature models the latter are probably being restricted to some undesireable parameter ranges (see e.g. Efstathiou 1988 in *Large-Scale Motions in the Universe*, Vatican Study Week, eds Rubin & Coyne, Princeton U.P., p299).

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New observations (Hogan & Partridge 1989 ApJ **341**, L29) using the VLA at 15GHz give the first interferometer limits at subarcmin scales at this frequency, at which confusion noise from background radio sources can be expected to be much smaller than in previous VLA measurements, while the new very sensitive 8ghz system at the VLA promises to give improved limits on scales 10″ to 2′. On these scales it is likely that one will first detect not primordial perturbations but fluctuations due to the integrated levels of 1 to 7×10^{-6} have been predicted for then Sunyaev-Zeldovich effect of clusters of galaxies at high redshift (Cole & Kaiser 1988 MNRAS **233**,637; Thomas & Carlberg 1989 MNRAS **240**,1009). Kreysa & Chini (1989, in Proc. of the Third ESO-Cern Symposium, *Astronomy, Cosmology and Fundamental Physics*, ed. Caff et al., Kluwer, Dordrecht, p433) have set a limit of $\Delta T/T \leq 2.6 \times 10^{-4}$ on a scale of ~30″, which is a significant constraint on theories involving early generations of dust-containing objects. A useful review of small-scale anisotropy observations is given in Lawrence (1990, in *The Cosmic Microwave Background: 25 Years Later*, eds. Mandolesi & Vittorio, Kluwer, Dordrecht, p33), and on all scales by Partridge (1988 Rep.Prog.Phys.**51**,647).

Further data taken over successive seasons at OVRO, has now given profiles for the Sunyaev-Zeldovich effect in three clusters-0016+16, A665 and A2218 (Birkinshaw 1990, in *The Cosmic Microwave Background: 25 Years Later*, l.c.). The central decrement in A2218 has been used together with GINGA X-ray data by McHard et al. (1990 MNRAS **242**, 215) to determine the Hubble constant as $24^{+13}_{-10}\mathrm{kms^{-1}Mpc^{-1}}$. However, Birkinshaw (1990) finds $H_0 = 60 \pm 20\mathrm{kms^{-1}}$ using the cluster A665 and suggests $H_0 \sim 50\mathrm{kms^{-1}Mpc^{-1}}$ using A2218. To turn to these estimates into a practical method of measuring the distance to clusters, more accurate and spatially resolved microwave background and X-ray measurements of clusters are needed. Both should be forthcoming in the next few years.