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DIVISION X: RADIO ASTRONOMY

(RADIOASTRONOMIE)

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Commission 40: Radio Astronomy

1. Introduction

Radio Astronomy has seen important advances in the last three years. New instruments and new sophisticated technologies allowed extremely deep radio observations, which have brought to the definition of new radio source populations. Studies of regions very close to the central engine of the powerful radio sources have been possible with the higher angular resolutions reached by space and millimeter VLBI. The development of radio spectroscopy has opened new ways to the physical and chemical investigation of the Galactic molecular cloud regions and of the chemical evolution of extragalactic systems. The extension toward higher frequencies has represented a powerful tool for the studies of star-forming galaxies and molecular clouds. The study of non thermal processes in galaxy clusters has largely progressed opening new lines of investigation. The comparison with observations in other frequency domains has allowed a more comprehensive insight of the physical phenomena in radio sources.

This report does not claim to be complete, but gives a sample of instrumental developments and scientific achievements.

2. New Developments at the Telescope Facilities

2.1. Centimeter-Wavelength Facilities

Arecibo Observatory, NAIC

The Arecibo 305-m radio telescope is available for astronomical observations at wavelengths between 6 m and 3 cm (frequencies of 47 MHz – 10 GHz) and in the declination range of −1 to +38 degrees. The 327- and 610-MHz receivers are currently undergoing upgrading to improve performance. Preliminary observations with the X-Band receiver (8-10 GHz) have been obtained and this new system is expected to have a sensitivity in the range of 2 to 4.5 K/Jy. A 6.0 – 8.0 GHz receiver is planned for 2003. At present, Arecibo commits up to 4% of its observing time to VLBI. Work on the primary reflector adjustment is in progress with significant improvements in performance already achieved. (http://www.naic.edu)

Australia Telescope National Facility (ATNF)

The six-element Compact Array in Narrabri (ATCA) is being upgraded to cover the bands 16-25, 30-50 and 80-115 GHz. First light on two antennas with the new 3 mm receivers was obtained in late 2000. At present, 3 of the 6 antennas of ATCA have 3 mm receivers. A four-channel atmospheric monitoring system will provide phase correction. Fu-

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ture upgrades may include monitoring receivers at 180-220 GHz and a 10 Gbit/s correlator. (http://www.atnf.csiro.au)

Effelsberg Radiotelescope - Max Planck Institute for Radio Astronomy (MPIfR)
The MPIfR is heavily involved in a number of large international radio astronomy projects. Numerous instruments have been built by MPIfR for use on other telescopes. New 5 and 11 cm receivers as well as 7 beam Ka and L band arrays are being build for the Effelsberg 100-m telescope. (http://www.mpifr-bonn.mpg.de)

Giant Metrewave Radio Telescope (GMRT)
The GMRT is located near Pune, India, and is operated by the National Centre for Radio Astrophysics (NCRA-TIFR). It consists of 30 fully steerable parabolic dishes, each 45 m in diameter. The GMRT telescope is already operating at 5 frequencies, 150, 233, 327, 610, and 1420 MHz. A 50 MHz system is being developed. A 30-antenna FX-based 256-channel correlator with a bandwidth of 16 MHz is operational. Special purpose back ends for the GMRT include a coherent de-disperser and search engine for pulsars. (http://www.gmrt.ncra.tifr.res.in)

Green Bank Telescope (GBT)
Outfitting and commissioning of the GBT started in fall of 2000. A first call for early science proposals has been made. At present, available observing modes include spectral line, continuum, pulsar, and VLBI/VLBA. Receivers include (in GHz): 0.290-0.920, 1.15-1.73, 1.73-2.60, 3.95-5.85, 8.0-10.1, 12.0-15.4 and 18.0-26.5. The higher frequencies will become available progressively. (http://www.gb.nrao.edu/GBT/GBT.html)

Institute of Radio Astronomy, Ukraine
The giant decameter wavelength radio telescope UTR-2 (150,000 m2) and the URAN VLBI system have been upgraded. The RT-70 telescope in Evpatoria, Crimea, is in operation from 0.3 to 4.8 GHz. (http://www.ira.kharkov.ua)

Instituto Argentino de Radioastronomia (IAR)
IAR operates two 30 meter radio telescopes. One is mainly dedicated to line observations (HI, OH, various recombination lines in the 1420 – 1720 MHz band). The second one is mainly dedicated to continuum polarimetry studies. The polarimetric receiver for the continuum and CH line near 3.3 GHz is now operational. (http://www.iar.unlp.edu.ar)

Istituto di Radioastronomia, Italy (IRA)
The Institute operates two stations, respectively in Medicina (Bologna) and Noto (Siracusa), with a total of 3 radio telescopes: The "Northern Cross" (600 m x 600 m) mainly for pulsar observations and 2 single-dish antennas (32 m) designed mainly for VLBI observations. In the last three years the Noto antenna was implemented with a system of active optics, allowing the on-line correction of gravitational deformations. The parabola can now observe at 40 GHz with an efficiency of 40%. The Institute is building a 64 meter parabola, Sardinia Radio Telescope (SRT), in San Basilio (Sardinia). (http://www.ira.cnr.it/)

Jodrell Bank Observatory (JBO)
The University of Manchester, through JBO, runs the UK National Facility for radio astronomy. It consists of MERLIN, a sensitive six-element interferometer network (seven when the Lovell Telescope is included) with baselines between 11 and 217 km that routinely produces radio images with an angular resolution matching that of the Hubble Space Telescope. MERLIN will be upgraded to e-MERLIN. E-MERLIN will have much wider bandwidth than MERLIN and a 30-fold increase in sensitivity for continuum observations. It is expected to be completed by 2007. The National Facility is also a regular participant in European and global VLBI observations. An upgrade of the Lovell Telescope's surface is now complete and will permit operation at up to 10 GHz. This upgrade includes a new

reflecting surface, pointing control system and refurbishment of the track and foundations. (http://www.jb.man.ac.uk)

Mauritius Radio Telescope (MRT)

The MRT is a joint collaboration between the University of Mauritius, the Raman Research Institute, and the Indian Institute of Astrophysics. The MRT is located on Mauritius at a latitude of $-20°$ and operates at 151 MHz. It consists of a fixed east-west arm 2 km long, made of 1,024 helical antennas arranged in groups of 32. A north arm is made of 16 trolleys (each carrying four helical elements), movable over an 880 m railway track. The effective angular resolution of the telescope is $4' \times 4.6'$ when data is gathered at 64 different positions of the north-south elements. The MRT has completed data collection for a radio survey of the southern sky at 151 MHz with a sensitivity comparable to that of the 6C survey. (http://icarus.uom.ac.mu/mrt2.html)

Miyun Station Radio Telescope (MSRT)

The MSRT is operated by the Beijing Astronomical Observatory. A survey of the sky north of $+30°$ declination has been completed at 232 MHz, which comprises 33,348 radio sources and images of 152 fields. A phased-array mode has been developed for the MSRT. The observatory has received funding to construct a new 50-m diameter telescope which will be used for single-dish studies and VLBI observations.

(http://www.bao.ac.cn/bao/station/my/MSRT-e.html)

Very Large Array (VLA)

In cooperation with UNAM (Mexico) and MPIfR (Germany), the installation of 7 mm (40-50 GHz) receivers on all 28 VLA antennas is practically completed. This band is particularly useful for imaging thermal continuum and SiO sources. Using holographic maps, the figure of all the antenna surfaces has been adjusted for better efficiency. A real-time link to the Pie Town VLBA antenna has been established, providing a factor of 3 increase in the VLA angular resolution for northern sources (105 km baseline). The 22 GHz receivers are being upgraded to systems with three times better performance (50K) and they have been installed in 21 antennas. The plan is to have all VLA antennas equipped with new K-band receivers in mid-2003.

The proposal to transform the VLA into the EVLA (Expanded VLA) has been approved by the NSF. This phase of the VLA expansion will accomplish a major instrumentation upgrade for the VLA receiving system, including: (1) installation of InP HFET amplifiers to cover all frequencies from 1.2 to 50 GHz, (2) installation of a fiber optic IF transmission system with a bandwidth of at least 4 GHz, and (3) installation of a correlator with capability for both broadband continuum observations (4-8 GHz per polarization) and the very high frequency resolution needed for spectroscopy of thermal lines. This phase will increase the sensitivity of the array by a factor of ten or more and will be completed by the year 2010. A second phase of the VLA expansion plan would connect the imaging scale of the VLA with that of the VLBA. This requires the addition of approximately eight new antennas within 300 km of the VLA. Each of these antennas would be connected by optical fibers to the VLA correlator, forming a real-time array of 37 antennas. (http://www.nrao.edu/doc/vla/html/VLAhome.shtml)

Westerbork Synthesis Radio Telescope (WSRT)

The new multifrequency front end receiver systems provide eight observational windows between 250 MHz and 8.7 GHz. The DZB correlator system is now operative, together with a 160 MHz dual-polarization IF system. In tied-array mode the telescope is equivalent to a 95 m single dish, which supports VLBI operations and pulsar observations using a state-of-the-art pulsar processor. A major research effort is underway to investigate and implement RFI suppression and cancellation instrumentation at WSRT. This technology will be critical for the next-generation telescopes. (http://www.nfra.nl)

2.2. Millimeter and Submillimeter Wavelength Facilities

Berkeley Illinois Maryland Association (BIMA)

The BIMA Millimeter Array is a 10 antenna (6.1 meters in diameter) aperture synthesis telescope, which operates at wavelengths of 3 mm and 1 mm, at the Hat Creek Radio Observatory. The installation of high sensitivity optical guidescopes on the elements of the BIMA array have facilitated a very precise comparison of optical and radio pointing characteristics. (http://bima.astro.umd.edu)

Caltech Submillimeter Observatory (CSO)

CSO consists of a 10.4-meter diameter Leighton radio dish situated in a compact dome near the summit of Mauna Kea, Hawaii. In 2002, a background limited camera at 0.35 and 0.45 millimeters wavelength (SHARC II) was commissioned . The detector is a 12 x 32 bolometer array. The sensitivity is 4 times greater than that of SHARC I. The heterodyne receivers on the telescope were used to make the first detection of triply deuterated ammonia (ND3) in the interstellar medium. No other molecules containing three deuterium atoms have ever been detected in the ISM. (http://www.submm.caltech.edu/cso/)

Institut de Radioastronomie Millimetrique (IRAM)

IRAM - Interferometer

A substantial overhaul of all six elements of the Plateau de Bure interferometer was completed in September 2002. In spite of the difficulties imposed by access to the site by helicopter and ground transportation, the interferometer is expected to support observations in three configurations in the winter 2002-2003. An important recent result was the imaging of Vega and its dusty debris envelop at 3 and 1.3 millimeters wavelength. The envelope showed two dust concentrations which may have been created by the dynamical influence of an unseen planet in a highly eccentric orbit that traps dust in principal mean motion resonances. Substantial progress has been made in the correction of images for the effects of atmospheric phase fluctuations by the use of measurements at 13 millimeters of the atmospheric water vapor content. (http://www.iram.fr/IRAMFR/)

IRAM - 30m Telescope

Major instruments at the 30-m telescope include: (1) a set of four dual polarization receivers at 3, 2, 1.3 and 1.1 mm wavelength; (2) a 9 pixel heterodyne receiver array operating at 0.9 mm wavelength (HERA); and a 117 pixel bolometer array at 1.2 mm wavelength (MAMBO-2). In addition a powerful spectrometer was commissioned (VESPA), which can support HERA with 2000 channels per pixel or the eight standard heterodyne receivers with 3000 channels per receiver. Remote observing can be carried out from Madrid, Bonn, Granada, Grenoble and Paris. (http://www.iram.fr/IRAMES)

James Clerk Maxwell Telescope (JCMT)

SCUBA continues to be the most used instrument on the 15-m telescope. Several new instruments have been funded. These include: (1) ACSIS, a large spectrometer designed to handle heterodyne arrays; (2) HARP-B, a 16 element heterodyne array operating in the 0.85 mm band, undergoing test during the summer of 2002; (3) SCUBA-2, a 0.45/0.85 millimeter wavelength, wide field imager using state-of-the-art technology and multiplexed readouts; (4) THUMPER, a 7 element 0.2 millimeter wavelength array, to be commissioned in early 2003; and (5) ROVER, a new heterodyne polarimeter.
(http://www.jach.hawaii.edu/JACpublic/JCMT)

Nobeyama Millimeter Array

The Millimeter Array now consists of 6 transportable 10-m antennas, which are equipped with cryogenically cooled SIS receivers at 3, 2 and 1.4 millimeter wavelengths. The array can be used with the 45-m telescope as a seventh element to produce a 21 baseline array at all wavelengths (RAINBOW). A new FX correlator is capable of extremely high resolution of 31 kHz over a 32 MHz band. (http://spaceboy.nasda.go.jp)

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Owens Valley Radio Observatory Millimeter Array (OVRO)

The OVRO millimeter wavelength interferometer consists of six 10.4 meter telescopes with 35 micron surface accuracy. The Array is located on the floor of Owens valley at an elevation of 1200 m, and operates at 3 and 1.4 mm wavelength. Work has begun to combine the Array with the BIMA array at a higher site in the White Mountains to form a new array, CARMA, which will have 15 elements. The wavelength coverage will be extended to 0.87 mm. Operation is expected to begin in 2005. (http://www.ovro.caltech.edu/)

Submillimeter Array (SMA)

SMA is nearing completion on Mauna Kea and has begun limited scientific observations. Five of the projected 8 telescopes are in operation at 1.4 and 0.85 mm wavelength. Images of CO emission in Mars, M51, as well as many late type stars and regions of star formation in the Galaxy have been made. The flux density of SgrA* has also been monitored at 1.4 mm. In addition, preliminary observations with three elements at 0.44 millimeters have been made. Remote operation of the array can be carried out from Hilo, Cambridge and Taipei. Completion of the array is expected in 2003. (http://sma-www.harvard.edu)

2.3. Very Long Baseline Interferometry

The VLBI European Network (EVN) has concentrated on increasing the reliability of its operations while at the same time increasing the sensitivity of the observations carried out. A data rate of 512 Mbps is now a routine mode of operation, although limited by tape supply. The Shanghai telescope is now fully operational within the EVN; Urumqi in northwest China is approaching this status. Phase referencing observations are routine, following improvement of the correlator model and the station positions. A pipeline for calibrated data for both continuum and spectral line from the EVN has been put into operation at the Joint Institute for VLBI in Europe (JIVE). The capabilities of the EVN Mk4 data processor at JIVE have been steadily improved for both continuum and spectral line observations. Over-sampling is operational; pulsar gating and speed-up correlation have been tested successfully but are not yet operational. A project has begun to increase the current output data rate from 1.5 Mbyte/sec to 160 Mbyte/sec for wide-field imaging, recirculation for high spectral line resolution, and pulsar work.

The VLBA 3-mm observing band has reached its initial goal, with receivers having been installed at eight of the ten stations. A holography system has been developed with a goal of improving aperture efficiency of the VLBA antennas to 30% at 3 mm. Since the necessary surface upgrade will require refiguring of the subreflectors, a precision mechanical measurement system also has been procured. The first VLBI observations have been carried out on baselines to the Green Bank Telescope and Arecibo Observatory. Finally, a data-calibration pipeline has been developed and is being used for all continuum data between 1.4 and 15 GHz; extension to higher frequencies and spectral-line observations is well under way.

The end of the era of tape recorders for VLBI recording and data transport appears to be in sight. Developments in PC hard-disk technology (capacity and cost) have made this medium competitive with tape and potentially much easier to use. The MIT Haystack Observatory with financial support from NASA, NRAO, the EVN and other sources has developed the Mk5 system based on disks, and has deployed a prototype version. Both the NRAO and EVN have initiated programs to develop the necessary interfaces between the Mark 5 disc-based recording system (or alternatives) and the VLBA and EVN telescopes and correlators. Fibre-linked networks for VLBI are in use in Japan, replacing both tape and PC hard-disk, and providing real-time VLBI for the first time. The first experimental fibre-linked systems are under development in Europe and the US and can be expected to assume greater importance in the coming few years. An international e-VLBI Working Group has been established.

The HALCA satellite continued to produce high resolution images of AGN, masers and pulsars for individual observers, as well as to carry out a continuum survey. In 2002 the continuum survey was given the highest priority, with observations continuing at a rate of about 10 observations per month. Studies have continued on the second-generation VLBI telescope in orbit, VSOP-2. The RadioAstron project is now the highest priority space astronomy project in Russia with an expected launch date of 2006. It will observe at wavelengths of 92, 18, 6 and 1.35 cm. The southern hemisphere VLBI network, and the Coordinated Millimeter VLBI Array continued to operate during the period. (http://www.evlbi.org, http://www.aoc.nrao.edu/vlba/html, http://www.vsop.isas.ac.jp)

3. Telescopes Under Construction and Under Development

Atacama Large Millimeter Array (ALMA)

ALMA is a joint project of the U.S. National Science Foundation and the European Southern Observatory. Funding for the construction of the observatory was approved in July 2002 by both partners and a formal agreement will be signed in Chile in October 2002. When operational, hopefully in 2011, ALMA will consist of 64 12-meter antennas, capable of astronomical observations in all atmospheric windows from 30 – 900 GHz. The array will be located in the Chajnantor region of the Andes in Northern Chile, 60 km east of the village of San Pedro de Atacama. Over the last two years enormous effort has been expended in the design and development phase. With the recent approval of funding the project is now moving towards the construction phase (http://www.eso.org/projects/alma).

Large Millimeter Telescope (LMT)

The Large Millimeter Telescope Project is the joint effort of the University of Massachusetts and the Instituto Nacional de Astrofísica, Optica, y Electronica (INAOE) in Mexico. The LMT is a 50m diameter millimeter-wave telescope designed for principal operation at wavelengths between 1mm and 4mm. The telescope is being built atop Sierra Negra, a volcanic peak in the state of Puebla, Mexico. Site construction and fabrication of most of the major antenna parts is underway, with telescope construction expected to be complete in 2004 (http://www.lmtgtm.org/)

The Low Frequency Array (LOFAR)

LOFAR is a low frequency radio telescope, being developed by a consortium of three institutes. ASTRON in Dwingeloo (The Netherlands), MIT's Haystack Observatory (USA) and the US Naval Research Laboratory (Washington DC). The telescope will be a multi-element interferometer that consists of about 100 phased array stations. The operating frequency will run from 10-240 MHz, allowing to probe beyond the Epoch of Reionization to the era before galaxies formed. A key feature of the telescope will be the ability to perform simultaneous full sensitivity multi-beam observations (max. 8 beams). The total collecting area will exceed a square kilometer at the lowest frequencies. Locations for the array under consideration are: the North-East of the Netherlands, South-West USA (Texas-New Mexico) and Western Australia. A final site will be selected early in 2003. First observations are scheduled for 2006-2007. (http://www.lofar.org)

Square Kilometer Array (SKA)

Astronomers from around the world are planning the next generation of radio telescope, the Square Kilometer Array (SKA). The SKA will be a massive undertaking, costing about 1 billion of US dollars. Several viable concepts for the design of the telescope exist and are being aggressively pursued by engineering and research teams around the world. The International SKA Steering Committee (ISSC) expects to select the concept(s) which will deliver the best science in 2006. At the same time, the ISSC also expects to select a site, which will most probably lie in a radio-quiet region of the globe. The SKA will address an enormous range of science, for example it will study faint radiogalaxy populations, and HI across the Universe. It will enable the first true window to be opened on the transient sky (http://www.skatelescope.org).

4. Scientific Highlights 2000-2002

4.1. Our Galaxy

Stellar Radio Emission

A recent review on radio emission from non degenerate stars has been made by Güdel (2002). The brown dwarf LP944-20 was found to be a radio emitter (Berger et al. 2001), although other brown dwarfs surveyed have not been detected. The microquasar LS 5039 was proposed to be associated with an unidentified source in the Energetic Gamma Ray Experiment Telescope (EGRET) on board the COMPTON-Gamma Ray Observatory satellite, suggesting that microquasars may be associated with these enigmatic sources (Paredes et al. 2000). Circularly polarized radio emission was detected from the radio-jet X-ray binary SS 433 (Fender et al. 2000). Proper motions have been detected along the axis of several thermal jets (Rodriguez et al. 2000, 2001). The radio emission from several of the massive stars forming the Arches cluster near the Galactic center was detected (Lang, Goss & Rodriguez 2001). The first direct measurement of the speed of energy flow within an astrophysical jet was observed in Scorpius X-1 (Fomalont, Geldzahler & Bradshaw 2001).

Pulsars

Many exciting results have been achieved in pulsar research during the years 2000-2002. The Parkes Multibeam Survey was completed, resulting in a real boom of pulsar counting: 650 new pulsars, nearly doubling the sample (Morris et al. 2002; Manchester et al. 2001). Besides the quantitative aspects, the new sample contains a significant number objects intrinsically rare, but very interesting for their applications: new relativistic binary systems (Lyne et al. 2000; Kaspi et al. 2000), young energetic pulsars, potential counterparts of the Galactic EGRET sources (D'Amico et al. 2001a), a radio pulsar in a binary system with a very massive companion (Stairs et al. 2001).

A new sensitive search of the Galactic Globular Cluster systems carried out at Parkes has produced 12 new millisecond pulsars in 6 globular clusters which where not previously known to host radio pulsars. Among them there is a very intriguing system, the eclipsing binary pulsar PSR J1740-5340 in NGC6397 (D'Amico et al. 2001b) with a bright stellar companion (Ferero et al. 2001) which shows evidence of tidal distortions, an effect which was not observed so far in binary pulsars. Another outstanding result was the discovery of millisecond pulsars in the core of NGC 6752 showing a large acceleration toward the cluster center, indicative of the presence of a high density of unseen dark remnants in the cluster core, probably black holes.

Precise timing observations of a substantial sample of millisecond pulsars discovered in the globular cluster 47 Tucanae (Freire et al. 2001) has resulted in the first detection of ionized gas in a globular cluster.

Radio Supernovae

Bright and relatively nearby radio supernovae can be imaged and resolved with cm-VLBI. Expansion rates and decelerations have been measured in a number of them: SN1993J (Marcaide et al. 1997; Bartel et al. 2000), SN1979C (Marcaide et al. 2002), and SN1986J (Perez-Torres et al. 2002). Also a limit has been placed on the deceleration of young supernova remnant 43.31+592 in M82 (McDonald et al. 2001). The Australia Telescope Compact Array has monitored the expansion of SN1987A (Gaensler et al. 1997; Manchester 2002). SN1993J in M81 is the best studied case: its shell structure is very symmetric and expands self-similarly as a first approximation. SN2001gd, spectrally very similar to SN1993J but 3 times further away, is also being studied with VLBI.

Molecular Clouds and Star Forming Regions

The first evidence for a massive protostar with an accretion disk was provided by Shepherd et al. (2001). A detailed study to disentangle the contributions of circumstellar envelope and disk in young stellar objects was completed by Looney et al. (2000). Millimeter observations

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of star forming regions with arrays have been very successful in detecting dense cores that probably are the site of future star formation (Phillips et al. 2001). A major observational effort now under way is the search for high-mass protostars, and several candidates have been proposed (e.g. Furuya et al. 2002; Zhang et al. 2002). A complete search for dense cores in Taurus has been accomplished (Onishi et al. 2002). A new complete CO survey of the Milky Way is finished (Dame et al. 2001). The first results of the Submillimeter Wave Astronomy Satellite were presented in volume 539 of the ApJ Letters. The simplest sugar, glycolaldehyde (CH2OHCHO),was detected in Sagittarius B2(N) (Hollis et al. 2000).

4.2. Extragalactic sources

Line Emission and Absorption

In the last 3 years, several advances may be noted: the detection of CO line emission well outside the optical disk of galaxies, and in tidal dwarfs (Braine et al. 2001), or the detection of CO in low surface brightness galaxies, after long and negative searches (Matthews & Gao 2001). The first results of a large survey of the CO line with the BIMA interferometer are appearing, revealing the radial distribution, and the relation to bars, spirals, etc.. Unexpected disk structures in the distribution of CO gas have been detected in a number of elliptical galaxies (BIMA-SONG, 45 galaxies Regan et al. 2002). After several attempts to detect molecular gas in cooling flow galaxies at the center of galaxy clusters, CO line was detected in a few cooling flow galaxies (Edge 2001), revealing an order of magnitude of the molecular mass. A survey of atomic CI in galaxies is compared to CO emission and their relative properties as coolants estimated (Gerin & Philips 2000). The first detection of molecular gas in the shells of CenA has been reported, challenging the formation mechanism of shells (Charmandaris et al. 2000). This detection may explain the previous detection of HI in shells, and support the phase wrapping mechanism.

Active Galaxies and Quasars

Intraday variability in compact extragalactic radio sources has been shown conclusively to be caused by interstellar scintillation, rather than intrinsic variations within the quasar itself. Simultaneous observations of J1819+3845 with the VLA and Westerbork have shown that the variability seen at the two telescopes is offset in time by minutes, implying that the different parts of the Earth successively move through the same scintillation pattern. This indicates that the compact radio source sizes in scintillators are just a few microarcseconds, smaller than can be imaged by any telescope (Dennett-Thorpe & de Bruyn 2001). Interstellar scintillation is also supported by the recent finding with the VLA that weaker radio sources scintillate more strongly, presumably because they are smaller in angular extent (Lovell et al. 2002).

Dan Harris and collaborators (2002) report the discovery of X-ray emission aligned with the northern radio jet of the low power radio galaxy 3C 129, imaged by the VLA. Based on comparisons with other X-ray detections in low power radio galaxies, the favored explanation for the observed X-rays is synchrotron emission.

Marscher et al. (2002), using monthly imaging with the VLBA combined with RXTE monitoring, find that the X-ray emission from 3C120 dims every 10 months or so, followed a month later by a new radio component emerging from the nucleus. This is probably due to parts of the inner accretion disk breaking off and plunging into the black hole, fueling the emission of a new blob in the radio jet. This phenomenon is also seen in microquasars within our own Galaxy, and indicates that the same phenomenon is occurring over a range of about 10^9 in black hole masses.

Galaxy Clusters, Interactions

In the past 3 years significant advances have been made on the study of non-thermal processes in galaxy clusters. The properties of cluster radio galaxies have been investigated to understand how they are affected by the dynamic gaseous environment, in particular when the clusters are in the process of merging (see Feretti & Venturi 2002 for a review). It was confirmed that the environment does not increase the probability for elliptical galaxies to develop a radio source. On the contrary, the cluster environment could play an important role in the production of starburst emission.

Perhaps the most intriguing cluster sources are the diffuse large-scale radio halos and relics (e.g. Coma C). These radio sources establish the presence of relativistic particles and magnetic fields in the Intra Cluster Medium. A wealth of radio and X-ray data have allowed to sharpen our view of the processes involved (see review by Giovannini & Feretti 2002). New halos and relics (also in distant clusters) were found from radio surveys (NVSS and WENSS) allowing statistical studies. Individual objects have been studied in detail, models have been developed.

The clusters hosting radio halos are massive rich clusters with high temperature and high X-ray luminosity. The diffuse sources appear to be linked directly to the cluster merger activity and to the accompanying turbulence and shock reacceleration of the radio emitting particles.

The cluster large scale magnetic fields have been investigated from studies of the Rotation Measure of radio sources in or behind clusters. These studies have revealed that magnetic fields of strength of the order of microGauss, and coherence length of the order of kpc, are widespread in all clusters, even those not hosting radio halos or relics (see Carilli & Taylor 2002 for a review). The magnetic field intensities obtained by different approaches (Rotation Measure, equipartition, Inverse Compton) are presently discrepant and they still need to be reconciled.

4.3. Cosmology

Extragalactic Surveys

The Northern all-sky surveys carried out in the last '90s (NVSS, FIRST, WENSS) are completed and fully released. They provide a unique view of the radio sky at mJy flux levels.

The Sydney University Molonglo Sky Survey (SUMSS) is still ongoing and at present is 53% complete: an area of 3700 sq. degr. of the sky south of declination –30° has been imaged at 326 MHz, down to and an rms noise level of about 1 mJy/beam. In the mean time rapid progress has been made in exploring the radio sky at lower flux levels. At sub-mJy levels several surveys are available on scales of a few sq. degrees: e.g. the Phoenix survey (ATCA), the Bootes field (WSRT), the ELAIS North (VLA) and the ELAIS South (ATCA). The largest one is the ATESP 1.4 GHz survey carried out with the ATCA, which covers an area of 26 sq. degr. with an rms noise level of about 80 microJy.

At micro-Jy levels, larger and deeper surveys are in progress. After the HDF North (Richards et al. 2000), the HDF South has been covered at several frequencies with the ATCA (ongoing analysis). Other larger fields are the VLA-VIRMOS field (17 microJy rms noise over 1 sq. degr.) and the extension of the Phoenix survey which collects now about 2000 sources with fluxes down to 60 microJy (both studies are close to publication). Deeper VLA surveys (down to rms noise levels of the order of 1 microJy) are being produced.

High-z Radio Galaxies

Submillimeter observations of deep fields has recently revealed that the 850 microns background is essentially due to distant ultraluminous infrared galaxies. The spatial positions of these objects are obtained by radio-continuum surveys, since faint radio sources trace remote starbursts; the redshift of these high-z sources have been estimated by a radio-photometric redshift (ratio between centimetric and submillimetric flux), and are between 1 and 3 (Barger et al. 2000). CO and dust emission were detected in new high redshifts radio galaxies and quasars (Papadopoulos et al. 2000, Carilli et al. 2002). A radio-polarimetric survey of high-z radio galaxies suggests that the fraction of powerful radio galaxies with extreme Faraday rotation increases with redshift, as would be expected if their environment was denser at earlier epochs (Pentericci et al. 2000).

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Gravitational Lenses

The Cosmic Lens All-Sky Survey (CLASS) and JVAS (Jodrell Bank-VLA) surveys are the largest and most successful searches for arcsecond-scale radio-loud gravitational lens systems. Among several thousand sources examined, 19 confirmed and 3 candidate systems, currently under analysis, have been so far discovered. The time delay measurements between variations of two different components leads to the calculation of the Hubble expansion constant. A preliminary result from a lens system studied at Jodrell gives a value for $H_o \sim$ 65 km/s/Mpc. In addition it is possible to model the mass distribution of the intervening galaxies, and to estimate their masses. See http://www.jb.man.ac.uk/research/gravlens for references. A similar survey is being carried out in the southern hemisphere with the VLA and ACTA telescopes. So far 4 confirmed and 3 candidate systems have been discovered.

Cosmic Microwave Background

The CBI (Cosmic Background Imager) results released this year were the first to clearly show the damping tail of the anisotropy power spectrum. The CBI also saw evidence of excess power on fine ($l \sim 200 - 3500$) angular scales beyond that expected from primary density fluctuations. The most likely explanation for it is the Sunyaev-Zel'dovich effect (SZE) from distant clusters.

John Carlstrom, on behalf of the DASI (Degree Angular Scale Interferometer) team, announced the discovery of polarization in the Cosmic Microwave Background. The observed polarization, produced by electron scattering at recombination, confirms current models based on the angular power spectrum.

The MAP (Microwave Anisotropy Probe) satellite has been orbiting for a year now, and has completed the first-pass all sky maps at 22, 30, 40, 60, and 90 GHz. Maps and analysis are expected to be released in January, 2003.

The TopHat telescope, which rides on the top of a balloon, had a successful flight in the South Pole last January, observing structure on scales of 0.33-48 degrees in five bands between 150 and 650 GHz.

ACBAR (Arcminute Cosmology Bolometer Array Receiver has obtained a lot of fine ($l \sim 60 - 2700$) scale CMB data this year.

5. Radio Frequency Protection

One poorly known but very important task of radio astronomy is the protection of the radio astronomical frequencies. It is becoming increasingly difficult to protect radio astronomy observatories from interference as the use of the electromagnetic spectrum increases for both terrestrial and space-borne communications.

In the last three years, international committees (IUCAF, CRAF, CORF, etc.) have devoted a large effort in studying and coordinating the requirements of radio astronomers and to make these requirements known to the national and international bodies responsible for frequency allocations.

Meanwhile, other groups have studied technological solutions for interference mitigation: interference rejection schemes, novel types of modulation manifesting inherently low out-of-band emissions, state-of-the-art RF filter technology and how it may be advanced, antenna null steering, interference recognition, and data editing

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Lucia Padrielli
President of the Division

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