J. Andersen (ed.), Reports on Astronomy, Vol. XXIVA, 347–356.

DIVISION X: RADIO ASTRONOMY

(RADIOASTRONOMIE)

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Commission 40: Radio Astronomy

1. INTRODUCTION

Radio astronomy has seen major advances in both instrumentation and scientific discovery during the last three years. This report is not encyclopedic but is intended to show the breadth of activity in the field. Division X is a technique-based division, and radio telescopes are becoming increasingly more international in character and usage. For these reasons this report devotes considerable attention to advances in instrumentation. More complete information on radio telescopes and scientific advances in the field can be found at the following Web site: http://www.stsci.edu/science/net-resources.html

2. NEW DEVELOPMENTS AT TELESCOPE FACILITIES

2.1. Centimeter-Wavelength Facilities

Arecibo Observatory (NAIC)

A major upgrade of the 305 m telescope was completed in 1998. New equipment includes a Gregorian reflector, pointing system, spectrometer, operating system, and S-band radar. The pointing accuracy is 5″ and the sensitivity at 1.5 GHz is 10 K/Jy over a wide zenith angle. The new planetary radar at 2.4 GHz has an average power of 1 MW. The primary surface is being reset to bring its rms deviation from 5 to 2.2 mm. (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. The front ends will be HEMT amplifiers. A four-channel atmospheric monitoring system will provide phase correction. Future upgrades will include receivers at 180–220 GHz and a 10 Gbit/s correlator. On the Parkes telescope, the 13-beam heterodyne receiver system at 21 cm has been in operation since March 1997. (http://www.atnf.csiro.au)

Giant Meterwave Radio Telescope (GMRT)

The construction of the GMRT near Pune, India, by the National Centre for Radio Astrophysics (NCRA-TIFR) has been completed. In partial operation since 1998, it consists of 30 fully steerable parabolic dishes, each 45 m in diameter. The frequency bands 300–350 MHz and 1000–1450 MHz are fully operational. Feeds and receivers for the bands near 150 MHz, 240 MHz, and 610 MHz are being tested. 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. The Raman Research Institute

https://doi.org/10.1017/S0251107X00003308 Published online by Cambridge University Press

has built three specialized digital signal processors for the GMRT: (1) the GMRT Array Combiner (GAC), which can add the FFT signals from all 30 antennas both coherently and incoherently, (2) a pulsar search preprocessor, which records suitably time-averaged multi-channel data from the GAC for off-line search, and (3) a pulsar polarimeter for detailed study of pulsar signals, including polarization. (http://www.ncra.tifr.res.in)

Instituto Argentino de Radioastronomia (IAR)

The IAR is testing a new polarimetric receiver for the continuum and CH line near 3.3 GHz.

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. The National Facility is also a regular participant in European and global VLBI observations. The Lovell Telescope continues to make valuable pulsar observations. An upgrade of the telescope's surface is planned to permit operation at up to 10 GHz. Manchester and Cambridge Universities are participating in a joint venture to study the CMB with the new VSA instrument, which is to be shipped to Tenerife.

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)

Max Planck Institute for Radio Astronomy (MPIfR)

Seven hundred panels of the 100 m telescope were replaced to improve high-frequency efficiency. Numerous instruments have been built by MPIfR for use on other telescopes.

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. So far, at least 5 BL Lac objects and other types of AGNs from selected candidates in the catalog have been identified by optical observations. A phased-array mode has been developed for the MSRT.

Very Large Array (VLA)

In cooperation with UNAM (Mexico) and MPIfR (Germany), 7 mm (40–50 GHz) receivers are being installed on all 28 VLA antennas. 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).

A proposal has been prepared to expand the capabilities of the VLA. First, a major instrumentation upgrade is planned 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. The 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)
A major upgrade of the 14 telescopes of the WSRT was completed in late 1998. The new multifrequency front end receiver systems provide nine observational windows between 250 MHz and 8.6 GHz. A DZB correlator system will be brought into complete operation in the middle of 2000, 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 such next-generation telescopes as the Square Kilometer Array (SKA) and the Low-Frequency Array (LOFAR). (http://www.nfra.nl)

2.2. Millimeter- and Submillimeter-Wavelength Facilities

Antarctic Submillimeter Telescope and Remote Observatory (AST/RO)
The 1.7 m off-axis telescope of AST/RO has been operating at the Amundsen-Scott South Pole Station since 1995. It is currently equipped with SIS receivers at 230, 490, and 810 GHz, and with three acousto-optical spectrometers. Measurements of the large-scale distribution of CI and CO continue. (http://cfa-www.harvard.edu/ adair/AST_RO)

Berkeley Illinois Maryland Association (BIMA) Array
With the addition of two new antennas and improved SIS mixers, the sensitivity of the BIMA array at 3 mm wavelength has doubled over the past three years. Low-noise receivers covering the 1 mm band were installed, and polarizers at both 3 and 1 mm were completed. New antenna pads extend the longest baseline to 1.9 km and also provide an ultracompact array for Sunyaev-Zeldovich measurements.

These improvements have allowed the imaging of 12 protoplanetary disks at 0.3″ resolution, of which 11 were found to be multiple systems. The first 1.3 mm interferometric dust polarization images showed that the polarization "hole" in lower-resolution maps of Orion-KL is due to a 90° flip in the polarization direction over a small region south of IRc2. The first interferometric detections of the Goldreich-Kylafis polarization of molecular lines allowed the mapping of magnetic field morphologies in star-forming regions. The Sunyaev-Zeldovich effect toward 27 galaxy clusters was measured. The array's large field of view allowed galaxy mergers in their earliest stages to be imaged and showed that atomic gas is converted to molecular gas earlier than previously thought.

Future plans include installing multichannel water vapor correlation spectrometers to make real-time corrections for atmospheric phase fluctuations, increasing the bandwidth from 830 MHz to 8 GHz, and developing dual polarization receivers using MMIC amplifiers, which will allow measurement of the Zeeman effect in CN.
(http://bima.astro.umd.edu/bima)

Caltech Submillimeter Observatory (CSO)
The CSO is now fully equipped for coverage of spectroscopic and mapping requirements in the atmospheric windows from 190 GHz to ~ 900 GHz. A 20-pixel linear bolometric

camera (SHARC) operates at 350 μm, 450 μm, and 870 μm in both mapping and pointed-deep integration mode. A wideband 16-element focal array receiver operated at 492 GHz (CHAMP), built by MPIfR, has been successfully commissioned at CSO. Future plans include Bolocam, a 151-pixel, wide-field camera operated at 1.1 mm, 1.4 mm, and 2.1 mm, and SHARC II, a 6×32-element camera operated at 350 μm and 450 μm with much better sensitivity than the current SHARC camera. A new IF system and an active control system for the telescope panels are planned. (http://www.submm.caltech.edu/cso)

Heinrich Hertz Telescope (HHT)

The HHT, operated by the Submillimeter Telescope Observatory for MPIfR and the University of Arizona, began regular observations in October 1997. The first astronomical measurements with a hot-electron bolometer (built by the Smithsonian Astrophysical Observatory) were made in March 1998 and continued in the 1998–1999 observing season. Images of eight galactic and extragalactic sources have been made in the CO J=7–6 line at 806 GHz. The rms surface accuracy of the reflector is now 12 μm, and the rms pointing accuracy is $2''$. (http://maisel.as.arizona.edu:8080/smt.html)

Institut de Radioastronomie Millimétrique (IRAM)

A fifth element was added to the IRAM interferometer on Plateau de Bure. The east-west baseline has been extended to 408 m. The sixth element is under construction but will be delayed because of the cable car accident in July 1999, which has had a serious impact on operations and development. Transportation of the five-ton central hub to the site remains an unsolved problem. On the 30 m telescope at Pico Veleta, the receiver cabin has been refurbished and eight new-generation SIS receivers are available, covering the 3, 2, and 1.3 mm bands. A new 37-pixel bolometer array (MPIfR) operates at 250 GHz with a sensitivity of 40 $\mathrm{mJy\,s^{1/2}}$. (http://iram.fr)

James Clerk Maxwell Telescope (JCMT)

The major instrument on the JCMT over the past three years has been the Submillimeter Common User Bolometer Array (SCUBA), which has been in regular service since May 1997 (Holland et al. 1999). The long-wavelength array (750–850 μm) has 37 pixels, each with a diffraction-limited resolution of $14''$; the short-wavelength array (350–450 μm) has 91 pixels of $7''$ resolution. The instrument led to the discovery of a new population of luminous, dusty galaxies at high redshift (e.g., Blain et al. 1999). In 1999 a major upgrade program began, which included an active surface adjustment system, a 16-pixel heterodyne array at 345 GHz (HARP), and a powerful new spectrometer (ACSIS). (http://www.jach.hawaii.edu/JACpublic/JCMT)

Mount Fuji Submillimeter Telescope

The University of Tokyo, the Institute for Molecular Science, and The Nobeyama Radio Observatory operate a 1.2 m telescope on the 3700 m summit of Mt. Fuji. Its principal task is to map the CI lines at 492 and 809 GHz.

Nobeyama Radio Observatory (NRO)

The new array (the Rainbow Array) consisting of the six elements of the Nobeyama Millimeter Array (NMA) and the 45 m telescope is operating at 3 and 2 millimeters. A 10 m telescope with a carbon fiber backup structure and lightweight machined-aluminum panels is under construction as a prototype element for the proposed Large Millimeter and Submillimeter Array (LMSA). The LMSA may be merged with ALMA to realize a more powerful combined instrument. (http://www.nro.nao.ac.jp/index-e.html)

Owens Valley Radio Observatory Millimeter Array (OVRO)

Over the last three years, OVRO has doubled its baselines to 440 m NS and 400 m EW, providing resolutions down to 0.4″ at the highest operating frequency of 265 GHz. The usable system bandwidth has been increased from 1 to 4 GHz. A scheme to measure and compensate for atmospheric phase variations by monitoring the 22 GHz water line emission has also been successfully implemented.

CO emission has been detected from the high-redshift, possibly primeval, galaxies discovered at submillimeter wavelengths. New 0.5″-resolution images of CO and 1.3 mm dust continuum emission in Arp 220 show counter-rotating disks of gas in the double nucleus of this ultraluminous infrared galaxy. The speed and sensitivity of the array have been critical in surveying CO in 39 nearby active galaxies to probe central morphologies and nuclear accretion mechanisms. A large-scale mosaic of 50 fields in the Serpens star-forming core has demonstrated that the mass distribution of 26 prestellar concentrations is consistent with the field star IMF, implying that stellar masses are determined at early stages of cloud condensation. (http://www.ovro.caltech.edu/mm/main.html)

2.3. Very Long Baseline Interferometry

New instrumentation for VLBI includes the HALCA satellite, launched in February 1997 by ISAS. The onboard 8 m antenna operates at 1.6 and 5 GHz as an element in ground-based arrays. It has been producing high-resolution images of AGN, pulsars, and masers (Hirabayashi et al. 1998). The Mark IV system, developed at Haystack has been in operation for several years. The maximum data rate is 1 Gbit/s. There are currently four processors in the USA and Europe and about 20 record stations in the field. The Joint Institute for VLBI in Europe (JIVE) began operating one of the Mark IV processors in October 1998 for the European VLBI Network (EVN). It can handle 16 stations. In China the Sheshan Station and Urumqi stations have been upgraded to Mark IV systems with help from EVN/JIVE. Haystack Observatory operates the Coordinated Millimeter VLBI Array at 3 and 2 mm.

The Japanese space agency plans to build a second-generation VLBI station in orbit, VSOP II. Farther in the future, the proposed NASA ARISE mission would place a 25 m telescope with a shortwave limit of 3 m in a 50,000 km orbit. This instrument would allow imaging resolution of 10 μas, or 3 Schwarzschild radii in the core of M87. Recent images at 7 mm wavelength from the VLBA plus seven other stations have revealed that the jet narrows at its base at a radius of about 30 Schwarzschild radii, with an opening angle of about 60 degrees (Junor, Biretta, & Livio 1999).

Emphasis at the VLBA has been on software development, which has made the system more user-friendly. Other activities include the increased use of dynamic scheduling to optimize observing time under conditions of poor weather or instrumental malfunction, the development of 512 Mbps recording, pulsar gating, easier integration of non-VLBA antennas, and the installation of 3 mm receivers on four of the antennas. Additional 3 mm receivers are being constructed with support from the MPIfR. About half of VLBA observing time is used by scientists from outside the United States.
(http://www.nrao.edu/doc/vlba/html/VLBA.html)

3. TELESCOPES UNDER CONSTRUCTION

Large Millimeter Array (ALMA)

ALMA is a joint project of the U.S. National Science Foundation (NSF) and a consortium of European institutions organized as the European Coordinating Committee (ECC). Guided by a Memorandum of Understanding (MOU) signed by participants in June 1999, the goal is to create an imaging array of 64 antennas, each 12 meters in diameter, capable of astronomical observations throughout all the atmospheric windows from 40 to 900 GHz. The array will be located high in the Altiplano of northern Chile at an altitude of 5000 m.

The ALMA Project subsumes the U.S. Millimeter Array (MMA) Project and the European Large Southern Array (LSA) Project. The NSF-ECC MOU covers the initial design-and-development phase in the period 1999–2001. Contracts were let for prototype antennas in late 1999. If all goes well, interim science operations can be expected in 2005, with completion and full operations by the end of the decade. Japan may join the project. (http://www.mma.nrao.edu)

Brazilian Decimetric Array

INPE has begun the construction of a decimetric array at Cachoeira, Paulista, Brazil. It will be a radio heliograph consisting of 26 parabolic dishes, each 4 m in diameter, operating in the frequency range 1.2–1.7 GHz.

Green Bank Telescope (GBT)

The GBT is a clear aperture, fully steerable 100 m telescope designed for operation at frequencies from 100 MHz to 100 GHz. The unblocked aperture of the GBT will greatly reduce RFI scattering into the receiver. It will also eliminate spectroscopic standing waves generated by reflections between feed and subreflector, which will facilitate observation of faint, broad spectral lines. The primary surface of the GBT consists of 2,000 panels, all of which are mounted on motor-driven actuators. The actuators are controlled by a laser interferometer system that repeatedly measures the surface figure. Commissioning observations are scheduled for the first quarter of the year 2000. (http://info.gb.nrao.edu)

Large Millimeter Telescope (LMT)

Mexico and the United States (University of Massachusetts) are building a 50 m telescope (LMT) on Cerro LaNegra mountain in central Mexico. This is the largest scientific project ever undertaken by the government of Mexico, which will provide half of the funding. Critical design work for the LMT is being done by the MAN corporation in Germany. An all-steel construction is planned. Operations are expected in 2003. (http://binizaa.inaoep.mx)

Sardinia Radio Telescope (SRT)

The SRT, a 64 m parabolic telescope with an active surface for the mirror segments allowing operation from 0.3 to 100 GHz, is under construction at San Basilio, Sardinia. (www.ira.bo.cnr.it)

Submillimeter Array (SMA)

The SMA is a joint project of the Smithsonian Astrophysical Observatory and the Academia Sinica in Taiwan. Two of the eight 6 m antennas have been operating on Mauna Kea at 230 and 345 GHz since September 1999. Once in full operation, the array will cover all bands from 180 to 900 GHz and will include the JCMT and CSO as elements. All the hardware is expected to be in place by the end of 2001. (http://sma2.harvard.edu)

4. TELESCOPES UNDER DEVELOPMENT

Combined Array for Research in Millimeter-wave Astronomy (CARMA)

Discussion continues about combining the six 10.4 m antennas of OVRO and the nine 6.1 m antennas of BIMA at a high-altitude (2700 m) site in the Inyo Mountains of California (near OVRO) to form a new, more powerful array. Such an instrument would provide high-quality, resolved images of solar system objects, protostars, protoplanetary disks, and galaxies—both nearby and in the early Universe. Improved atmospheric transmission at the new site would enable routine observations in the 1.3 mm band (205–265 GHz) and occasional use at 850 μm (345 GHz). The maximum baseline is expected to be about 3 km.

Low-Frequency Array (LOFAR)

Dutch and U.S. radio astronomers are planning the construction of a low-frequency array operating between 15 and 150 (possibly 300) MHz with an effective collecting area of about a square kilometer at the lowest frequency. LOFAR will be an electronically steerable, diffraction-limited multibeam instrument operating in this little-studied region of the radio spectrum. The probable location is the VLA site in New Mexico.

Square Kilometer Array (SKA)

Radio astronomers from the Netherlands, Australia, Canada, China, the United States, and other countries are discussing plans for building a next-generation radio telescope, known as the Square Kilometer Array (SKA), with an effective collecting area of 1 million square meters. An international steering group has been formed to coordinate the activity, including the design of the antenna elements being pursued in different countries. Precursor instruments include LOFAR, the 1HT, and KARST. (http://www.nfra.nl/skai)

5. SCIENTIFIC HIGHLIGHTS, 1997–1999

5.1. Cosmic Microwave Background

Sensitive CMB observations have been made from the ground (e.g., Chilean Altiplano, Antarctica) and from balloons, with sensitivities of 10 μK or less per beam. Data cover frequencies from 30 to 300 GHz and angular scales from arcminutes to radians. The first Doppler (acoustic) peak at $\sim 1^\circ$ scale (angular frequency $l \sim 100$) appears to have been identified, showing that the fluctuations are primordial in origin (e.g., Miller et al. 1999; Hancock et al. 1998). The Sunyaev-Zeldovich effect has been measured toward more than 25 clusters with BIMA and other instruments (Carlstrom et al. 1999).

5.2. Gravitational Lenses

Important areas of activity are (1) the search for new lenses using surveys of radio sources, (2) time-delay measurements, which constrain the Hubble constant, and (3) studies of lensing galaxies and lensed objects to constrain the matter distribution at high redshifts. With the Cosmic Lens All-Sky Survey (CLASS) and JVAS (Jodrell Bank–VLA) surveys, at least 16 new gravitational lenses have been found among the 16,000 flat-spectrum sources examined. Similar searches have begun in the southern hemisphere with the VLA and ATCA. A search for lensed radio lobes is being carried out by combining data from the FIRST and APM surveys. Many of the newly discovered lenses and the previously known ones have been monitored for time-delay measurements. Time delays have been measured in B0218+357, B1608+656, and B1600+434. The longstanding discrepancy between the optical and radio delay measurements for 0957+561 has been resolved; all data are in agreement with the optical value of 417 $\pm$ 3 days (Haarsma et al. 1999). In PKS1830-211, in which molecular absorption lines occur against only one of the two radio components, a novel technique of combining the depth of the HCO+ line and the total continuum flux has been used to deduce the time delay.

5.3. Extragalactic Source Structure

The significant improvement in sensitivity and angular resolution of radio telescopes has allowed imaging of radio sources with unprecedented detail, from the pc to the kpc scale. Images of strong radio sources with HALCA have shown the existence of edge-brightened jets. The studies of radio sources from the small to the large scale are drawing an increasingly complete picture of the structure, dynamics, and evolution of these objects.

5.4. Extragalactic Surveys

The NRAO VLA Sky Survey (NVSS), covering the sky north of $-40°$ declination at 20 cm with $45''$ resolution, is essentially ($> 99\%$) complete. Images in both total intensity and linear polarization with a typical noise level of 0.45 mJy/beam are available. The Faint Images of the Radio Sky at Twenty centimeters (FIRST), providing images with $5''$ resolution at 6 GHz and a typical rms of 0.15 mJy, currently covers an area of about 6000 square degrees. The Westerbork Northern Sky Survey (WENSS) covers 3.14 sr north of $+30°$ declination at 326 MHz, with $54'' \times 54''$ csc (dec) resolution in total intensity and linear polarization. The Sydney University Molonglo Sky Survey (SUMSS) is a sensitive radio imaging survey of the sky south of declination $-30°$ being carried out at 843 MHz, with resolution of $43'' \times 43''$ csc (dec) and an rms noise level of about 1 mJy/beam. The survey is 25 percent complete (April 1999) and is progressing at a rate of more than 1000 square degrees per year. Deep VLA surveys covering the HDF (Richards et al. 1998) and other fields reach radio sources fainter than 10 μJy. Most of the microjansky radio sources appear to be associated with active star-forming regions at moderate redshift. Others appear to be very red objects associated with heavily obscured starburst galaxies at high redshift.

5.5. Extragalactic H I Spectroscopy

Deep H I synthesis imaging obtained with various interferometers (ATCA, VLA) has been used for investigating the degree to which the environment affects the evolution of present-day spiral galaxies in cluster. Galaxies near the cluster centers are H I-deficient or characterized by perturbed gas distribution. Early spirals are more easily depleted of neutral hydrogen than late-type ones. Progress has been made in redshifted radio absorption-line studies. Several redshifted 21 cm absorption systems have been detected, and kinematical studies of the absorbing components have been performed.

5.6. Low-Frequency Radio Sky

First maps of extragalactic objects (Virgo A, 3C129, Coma Cluster, Perseus clusters) have been obtained with the new VLA observing system operating at 74 MHz. These results show that self-calibration can remove ionospheric distortions over wide fields of view. The region below 150 MHz is one of the least explored in the radio domain. The VLA provides an angular resolution of $\sim 25''$, 8 h sensitivity of 25 mJy, and can synthesize a $12°$ field of view in a single pointing. This system opens the low-frequency regime to high-resolution and high-sensitivity imaging.

5.7. Molecular Clouds and Star Formation

Dusty star-forming galaxies at high redshifts have been detected at submillimeter wavelength in the Hubble Deep Field (HDF) and in other regions of the sky (e.g., Eales et al. 1999). Optical and ultraviolet observations of high-redshift galaxies had indicated that the peak star formation in the Universe occurred between redshifts of 1 and 1.5. However, star formation is very often hidden at optical wavelengths because of extinction by the surrounding dust. The new submillimeter observations imply a star-formation rate, for redshifts between 2 and 4, five times higher than that inferred by optical and ultraviolet observations.

Important advances are occurring at the millimeter and submillimeter wavelengths, where redshifted rotational lines of CO and dust emission have been observed toward high-redshift objects, using the IRAM interferometer and other instruments (e.g., Combes, Maoli, & Omont 1999).

Numerous high-resolution millimeter detections of dust and gas emission from quasars and radio galaxies demostrate that this emission can directly trace large masses of interstellar material at high redshift (e.g., Downes et al. 1999).

https://doi.org/10.1017/S0251107X00003308 Published online by Cambridge University Press

Discovery by the HST of the opaque fingers in the Eagle Nebula, and subsequent millimeter, submillimeter, and mid-IR observations, have allowed the identification of molecular cores that, evolving in the tips of the fingers and subject to strong external UV radiation, appear to be in the earliest stages of protostellar formation (White et al. 1999).

High-sensitivity measurements of the CO image from protoplanetary disks such as DM Tauri reveal the dynamical properties of these disks (Guilloteau & Dutry 1998). Surveys of many molecular transitions provide a technique for determining their chemical abundance (Dutrey, Guilloteau, & Guelin 1997). Compact protoplanetary disks have been found around stars of a young binary system (Rodríguez et al. 1998).

A sensitive survey of the ρ Ophiuchi cloud in 1.3 mm continuum emission has revealed 58 starless cores. The mass-density function of these prestellar cores is similar to that of the IMF, suggesting that these cores are the direct progenitors of individual stars (Motte, Andre, & Neri 1998). Similar results have been obtained for the the Serpens molecular cloud.

5.8. Masers

Bright OH megamaser galaxies can be detected at redshifts between 1 and 3 with existing radio telescopes, and radio spectroscopic surveys at frequencies of 400 to 1000 MHz form independent and important tests for merger rates as a function of time. Twenty-two water vapor masers have been identified in the nuclei of galaxies (e.g., Moran, Greenhill & Herrnstein 1999). Proper motions of about 31 μas yr^{-1} have been measured in the maser in NGC 4258, from which a direct trigonometric distance of 7.2 ± 0.3 Mpc was estimated (Herrnstein et al. 1999). Frequent imaging of the SiO masers in late-type stars has provided a new tool to trace gas motions in stellar envelopes (e.g., Diamond & Kemball 1999). Images of SiO and water vapor masers toward a high-mass protostar in the Orion BN/KL region revealed coexisting conical bipolar and equatorial outflows (Greenhill et al., 1998)

5.9. Astrometry

VLBI positions of 212 sources accurate to less than 1 mas, forming the International Celestial Reference Frame (Johnston & deVegt 1999), were published by Ma et al. (1998). Relative positions of sources nearby in angle have been measured to an accuracy of 0.1 mas (e.g., Ros et al. 1999). The VLA FIRST survey produced a catalog of 26 stellar radio sources with accurate positions (Helfand et al. 1999). The rotation of the Galaxy was directly measured by observations of SgrA* against the extragalactic background (Backer & Sramek 1999; Reid et al. 1999).

5.10. Pulsars

The Parkes Southern Pulsar Survey was completed and found 101 new pulsars, including 17 millisecond pulsars (Manchester et al. 1996; Lyne et al. 1998). The Parkes Multibeam Survey, now about half complete, has already found more than 400 mostly young and distant pulsars (Lyne et al. 1999). When complete, it will double the number of known pulsars. Pulsar timing measurements have yielded proper motions for a large sample of millisecond pulsars (Toscano et al. 1999) and parallaxes for a few objects (e.g., Sandhu et al. 1997; Stairs et al. 1998). For the first time, significant values for five relativistic or post-Keplerian parameters were obtained for PSR B1534+12 (Stairs et al. 1998). Young, Manchester & Johnston (1999) discovered a radio pulsar with an 8.5-second period, much longer than any previously known period and beyond the range predicted by most emission mechanism models. Kramer (1998) detected a change in pulse width of PSR B1913+16 caused by geodetic precession.

This report was compiled by J. M. Moran from information supplied by K. R. Anantharamaiah, W. A. Baan, E. Berkhuijsen, L. Blitz, L. Bronfman, R. L. Brown, R. J. Davis, M. M. Davis, H. R. Dickel, L. Feretti, L. J. Greenhill, M. Inoue, K. J. Johnston, N. E. Kassim, K. I. Kellermann, A. Konovalenko, R. N. Manchester, L. Padrielli, R. S. Peng, A. I. Sargent, R. Schilizzi, J. B. Whiteoak, D. L. Wilner, and T. L. Wilson.

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