Millimeter/SubMillimeter Radio Astronomy in the US

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ABSTRACT

This summary contains short reports from Millimeter Wave and Submillimeter Wave Telescopes in the United States, including The Atacama large Millimeter Array, The Caltech Submillimeter Observatory, The Five College Radio Astronomy Observatory, The large Millimeter Telescope, The Submillimeter Telescope Observatory, The Berkeley-Illinois-Maryland-Association Millimeter Array, The Owens Valley Radio Observatory Millimeter Array, The Combined Array for research in Millimeter Wave Astronomy, and The SubMillimeter Array. In addition, there are special purpose instruments designed to study the Cosmic Background Radiation, which include, for the ground based instruments, The Cosmic Background Imager, the Degree Angular Scale Interferometer, and the Sunyaev-Zel'dovich Array.

THE ATACAMA LARGE MILLIMETER ARRAY

The Atacama Large Millimeter Array (ALMA) is an aperture synthesis telescope of 64 12-meter diameter antennas operating in the range from 3 to 0.4 mm. ALMA is a joint endeavor of the U.S. National Science Foundation (NSF) in partnership with the National Research Council (NRC) of Canada, and the European Southern Observatory (ESO) in partnership with Spain. ALMA will be built on the Chajnantor plateau at an elevation of 5000 meters in the Altiplano of northern Chile. With agreement of the NSF and the NRC, the North American side of the Project is being conducted by Associated Universities, Inc./National Radio Astronomy Observatory as the North American Executive agency. ESO is the European Executive agency for ALMA.

A construction start in FY2002 for ALMA was requested by the NSF; the U.S. Congress responded by authorizing construction funding of $12.5M to begin the Project. The NSF has requested $30M to continue the Project in FY2003. A decision by the ESO Council to begin construction on the European side in FY2002 is expected at the July 2002 Council meeting. With ESO Council approval, and with the signature of the Agreement for ALMA by all parties, the joint 9-year construction project will officially commence. The total Project cost is $552M year 2000 U.S. dollars. Opportunities for initial interim science observations with the first antennas are expected in 2006 or 2007 leading gradually as array capabilities grow to full science operations by the end of 2011.

THE CALTECH SUBMILLIMETER OBSERVATORY

The CSO is in the process of developing a new set of detectors for improved study of distant objects. There are two new cameras for study of continuum emission from dust. Bolocam, which has about 150 pixels and operates at 1 and 2 mm wavelengths, and SHARCII with about 400 pixels and operating at 450 and 350 microns. Bolocam is expected to make initial detections of objects and SHARCII to provide higher angular resolution data and SED information. Two kinds of detectors will be available for spectroscopic studies. Low resolution grating/FP spectrometers (R=1000) to detect lines and measure the redshift, and heterodyne SIS receivers to resolve the dynamical structure. The new series of receivers will use 4 SIS elements (2 polarizations and on-source/off-source pixels) for improved sensitivity and stability. The telescope surface is to be controlled to eliminate changes with elevation and so improve the high frequency performance.

Recent scientific discoveries include the detection of triply deuterated ammonia (ND3) in a variety of ISM large column density, low temperature regions. A new technique to determine the parameters of the ISM magnetic field has been developed. It uses the phenomenon of molecular-ion linewidth reduction as compared to comparable neutral species, due to ion gyration around the magnetic field lines. When combined with polarization and Zeeman measurements it fully determines the magnitude and direction of the magnetic field. (www.submm.caltech.edu/cso/)

FIVE COLLEGE RADIO ASTRONOMY OBSERVATORY 14M TELESCOPE

The Five College Radio Astronomy Observatory (University of Massachusetts) operates a 14m millimeter-wave antenna located in the Commonwealth of Massachusetts, USA. This antenna is instrumented for mapping of millimeter-wave spectral lines over large (degree) angular scales at the full resolution of the antenna. The front end is a focal plane array of 32 heterodyne receivers for the 85-115 GHz band. The array makes use of InP MMIc amplifiers developed in our laboratory for radio astronomy, which result in typical noise temperatures of 40-100K over the full receiver band. Each pixel of the receiver produces 15 GHz of instantaneous bandwidth which may be analyzed with 2 independent narrow band spectrometers for mapping of molecular clouds. Thus, maps of molecular emission from two molecular species may be made simultaneously. In addition, the central 16 pixels of the array are instrumented with wideband filterbanks for mapping external galaxies. On-the-fly mapping techniques are used to obtain the data with the focal plane array. The scientific use of the telescope is focussed on studies which make good use of this special spectral line imaging capability. Examples of recent scientific projects include: (1) the Boston University-FCRAO Galactic Ring Survey, which is a survey of 13CO covering 60 square degrees of the inner disk of the Milky Way; (2) an imaging survey of CO in approximately 20 Virgo cluster galaxies; and (3) wide field imaging of the CO emission in M33. (www.astro.umass.edu/ fcrao/)

LARGE MILLIMETER TELESCOPE

The Large Millimeter Telescope (LMT) is a joint project of the University of Massachusetts (UMass) in the USA and the Instituto Nacional de Astrofisica, Optica y Electronica (INAOE) in Mexico to build the world's largest filled-aperture radio telescope for use at short millimeter wavelengths. The LMT will have a diameter of 50 m, and it will operate with good efficiency at wavelengths as short as 1 mm. The telescope is being built as an "open-air" telescope with no radome or astrodome enclosure. Its system specifications call for an overall effective surface accuracy of 75 microns rms and a pointing accuracy of 1.0" rms. The Construction of the antenna is underway atop Volcan Sierra Negra, a 4600m peak in the state of Puebla, Mexico. The project is now well advanced, and the antenna is expected to be completed in 2004.

The large collecting area of the LMT will allow it to contribute significantly to many scientific areas. However, its greatest impact is expected to be in the exploration of the origin and evolution of galaxies through the study of millimeter spectral line and continuum emission from objects at high redshift. Construction of the initial LMT instrumentation is currently in progress, with many instruments tailored to this scientific objective. The initial complement includes: (1) a continuum focal plane array, which will be used for imaging surveys of the background and searches for protogalaxies; (2) a multi-band continuum receiver for measurement of spectral energy distributions of protogalaxies and observations of the Sunyaev-Zel'dovich effect; (3) an ultra wideband (40 GHz) spectroscopic receiver for conducting blind redshift searches on protogalaxies discovered in continuum surveys; (4) a 32-pixel 3mm focal plane array for spectral line observations; (5) a one-millimeter SIS heterodyne receiver for spectroscopic observations in the 210-275 GHz frequency band; and (6) spectrometers for molecular cloud mapping and extra galactic mapping with focal plane arrays. (www.lmt.gtm.org/)

THE SUBMILLIMETER TELESCOPE OBSERVATORY

The Submillimeter Telescope Observatory (SMTO) operates the Heinrich-Hertz- Telescope (HHT) on Mt. Graham, AZ, on behalf of the Steward Observatory (University of Arizona) and the Max-Planck-Inst. f. Radioastronomie, Bonn, Germany. Over the last three years, the SMTO staff have improved the surface accuracy of the HHT using holography with the LES 9 satellite. The present accuracy is between 15 and 17 microns. The pointing accuracy has been maintained at 2" RMS, over a period of 3 years. We are introducing optical pointing, which will allow us to reach 1" RMS, the HHT design specification. Observing projects at the HHT are carried out using priority (or queue) scheduling for frequencies higher than 345 GHz. The 'normal' spectral line observing is done with the facility SIS receivers at 200-280 GHz and 330-350 GHz. SMTO has a 1 channel SIS system at 460-492 GHz. Spectrometers are 3 AOS's with resolutions of 1 MHz (covering 1 GHz) and 370 kHz (covering 300 MHz), and filter banks with 1 MHz, 250 kHz and 62.5 kHz resolutions. SMTO also has a 19 channel bolometer camera covering the 330-350 GHz window. The most prominent milestone was the first measurement of the CO J=9-8 line at 1.037 THz from the ground with a heterodyne receiver, the Hot Electron Bolometer (HEB), from the Harvard-Smithsonian CFA. Further projects with the HEB are images of Orion KL in the CO J=7-6 line at 806 GHz, and ^{13}CO J=6-5 at 661 GHz, and images of a number of galaxies including M82, in the CO J=7-6 line. Further imaging has been done in the CI line at 492 GHz and with the 200-280 GHz system. In the last 2 years, the large over subscription in time was caused by requests for the bolometer in preparation for SIRTF launch. (www.maisel.as.arizona.edu:8080/)

THE OWENS VALLEY RADIO OBSERVATORY MILLIMETER ARRAY

OVRO operates a Millimeter Interferometer in the Owens Valley consisting of six 10.4m antennas situated on a T-shaped track. Receivers are available for both the 1mm and 3mm bands. Research is carried out over a wide range of scientific programs with a strong emphasis on high red-shift CO and star formation. There have been a number of technical advancements during the past three years. These include (1) the completion of the COBRA wide band correlator, a new spectrometer with 4 GHz bandwidth and 30 MHz resolution; (2) the deployment of 22 GHz water line monitors with cooled receivers on all antennas; (3) fixed tuned three millimeter receivers with 4 GHz of instantaneous bandwidth; (4) 2 GHz of spectral line coverage permitting, for example, simultaneous observations of ^{12}CO, ^{13}CO, and $C^{18}O$; and (5) new control software and hardware based on LINUX/CORBA/CANBUS. The water line monitor receivers permit correcting interferometric observations to delay residuals of 100 - 200 micrometers. (www.ovro.caltech.edu/mm/main.html)

THE COMBINED ARRAY FOR RESEARCH IN MILLIMETER ASTRONOMY

(CARMA) is a 23-antenna heterogeneous millimeter array under construction in the Inyo Mountains of eastern California. CARMA will merge the existing Owens Valley and Berkeley-Illinois-Maryland Association arrays into a single instrument focusing on pure research, technology development and student training. A new high-altitude site will enable routine 205-265 GHz observing, and may allow observations in the 345 GHz window. Eight additional 3.5-m antennas from the University of Chicago will also be integrated into CARMA when not imaging the Sunyaev-Zeldovich effect towards clusters of galaxies.

Over the past three years the project has refined its site candidates and begun the process of identifying a new high-altitude site. We have recently initiated an environmental analysis of our site candidates, all three of which are on Forest Service land. In 2000 a project manager was hired to guide the site process and oversee the array technical development. At present we are documenting the existing OVRO and BIMA hardware and software and developing/reviewing common designs for the merged array subsystems.

At first light, the array will observe at 12, 3 and 1.3 mm using a mix of SIS and MMIC-based receivers. A new, highly-flexible correlator incorporating re programmable FPGA technology will process configurable subsets of the antennas specified according to the science objectives. Leading-edge water vapor radiometers will be used to correct for atmospheric opacity and signal phase fluctuations. CARMA will be capable of both high resolution and wide-field imaging, covering a range of angular scales unmatched by any current or planned millimeter-wave instrument. The high sensitivity, sub-arcsecond angular resolution and excellent uv-coverage of CARMA will ensure major advances in studies of the universe. The array will provide high-fidelity resolved images of solar-system objects, protostars, protoplanetary disks, and galaxies both nearby and at high redshift - directly addressing many key research areas in astronomy and astrophysics. (www.mmarray.org/)

THE BERKELEY-ILLINOIS-MARYLAND-ASSOCIATION MILLIMETER ARRAY

The last three years marks one of the most productive periods for BIMA science and a fundamental shift in the kinds of science that researchers have been doing. BIMA is capable of producing the highest resolution at millimeter wavelengths of thermal sources, and a number of outstanding images of star forming regions have been produced. However, much of the work at BIMA is now going in the direction of making large-scale mosaics as well as large scale surveys. The largest millimeter-wave mosaic of any source was accomplished by the full CO imaging, at 13” resolution, of M33. The mosaic is about 1/2 degree square, and has almost 800 individual pointings. The imaging has produced the first complete catalog of GMCs in any spiral galaxy including the Milky Way, and promises to provide important information on the formation and evolution of GMCs. The BIMA Survey of Nearby Galaxies (SONG) was completed, a survey at $6''$ resolution of 44 nearby spirals. Maps of most galaxies consist of a 7 field mosaic, but also included is a complete CO map of M51 and its companion. A CO survey of more than 100 nearby dwarf galaxies is underway, with one of the aims to determine the dark matter distribution in dark matter dominated systems. The first result on NGC 4605 shows that the dark matter density distribution within 1 kpc of the center has a power law dependence of r$^{-0.6}$, contrary to the expectations of sophisticated high-resolution cosmological simulations. Among others, two outstanding results at high resolution come from observations of nearby star forming systems. In one, we have imaged a rotating, infalling disk in L1489 IRS in HCO+ 3-2 and 1-0. The former is at $2''$ resolution and is done at a frequency of 267 GHz. Second, the protoplanetary disk of HL Tau, imaged at a resolution of $0.25''$ at 220 GHz, has been shown to have a companion apparently embedded in the disk. On the technical side, the Array has now been completely converted to fiber for IF/LO distribution and telemetry to all of the antennas. In addition work is underway to provide water vapor radiometry for active phase correction. The detection is being done by the construction of a correlation radiometer which nulls the sky against a well calibrated variable thermal load with small enough thermal inertia to follow sky variations. The intention is to monitor the entire water line in 1 GHz channels to get information on the wings of the line as well as the core. Initial tests have proved promising. A method of absolute calibration of the sky signal to one 1made by building a two temperature nutating calibration device in the subreflector. Although the device provides much improved absolute calibration, the goal of 1% radiometry has not yet been achieved because of difficulties in measuring the coupling of the antenna to the calibrator.

THE SUBMILLIMETER ARRAY

The SMA is a combined project of the Harvard-Smithsonian Astrophysical Observatory and the ASIAA in Taiwan. It consists of an array of eight 6m antennas being installed on the summit of Mauna Kea in Hawaii to operate over the range 230 to 850 GHz. Initial operation is in three bands: 230 GHz, 340 GHz, and 650 GHz. There will be dual polarization, and all antennas are equipped with nodding secondaries. Sub arc-second angular resolution is expected. Receivers are excellent, with a temperature of 3hf/k achieved at 450 GHz in the laboratory. Four antennas are now in routine operation on the summit; the array should be complete in about one year. Early scientific results are promising. For example, a measurement of the CO(2-1) absorption in the atmosphere of Mars yields a good atmospheric model. There are plans for eventual operation with both the CSO and JCMT for enhanced sensitivity for both small scale and large scale structure in maps. (sma-www.harvard.edu/)

THE COSMIC BACKGROUND IMAGER

(CBI) is a 13-antenna radio interferometer operating in 10 1-GHz frequency bands from 26-36 GHz. The 90-cm diameter Cassegrain antennas are mounted in cylinders which provide 110 dB shielding against cross-talk between antennas. The 6-m tracking platform has three rotation axes - azimuth, elevation and the optical axis. The third axis of rotation is used to increase (u,v) coverage, to test for cross-talk, and also to facilitate polarization observations. The low noise amplifiers are based on indium phosphide HEMTs, and the system temperature is 30K. The instrument has been operating since January 2000 at altitude 5080 m in the Chilean Andes. The CBI is making extremely sensitive measurements of the cosmic microwave background radiation in the multipole range 400¡l¡3500, as well as of the Sunyaev-Zel'dovich effect in clusters of galaxies. (S. Padin, et al, 2002, PASP, 114, 83.)

THE ANGULAR SCALE INTERFEROMETER

DASI is a compact interferometer deployed at the South Pole Station to study angular structure in the cosmic background radiation at angular spectral scales of l=100 to l=900. This range spans the first three harmonically related acoustic peaks expected to be present in the background radiation. The array consists of 13 elements in 10 1GHz bands over 26-36 GHz. The elements are mounted on a flat plate which is in turn mounted on an alt-azimuth tracking mount. The face plate is also able to rotate, which both increases the uv coverage of the interferometer and also permits the evaluation of many systematic errors. In the first year of successful operation at the Pole, 32 fields of 3.4^o each were studied. All systematic errors were reduced to the level of basic receiver noise, and the expected acoustic peaks at l=200,500 and 800 were detected. (E. M. Leitch, et al, 2002, Ap.J, 568, 28).

THE SUNYAEV-ZEL'DOVICH ARRAY

The Sunyaev-Zel'dovich Array (SZA) is an interferometric array consisting of eight 3.5m telescopes equipped with low-noise HEMT amplifier based receivers operating at 26 - 36 GHz and 85 - 115 GHz. It will be co-located with the CARMA array. A digital correlator will process up to 8 GHz bandwidth for exceptional continuum sensitivity. The project is being led by by the University of Chicago with strong collaboration with Caltech and CARMA. The initial key project of the SZA is a deep survey covering 12 square degrees for galaxy clusters through their Sunyaev-Zel'dovich Effect (SZE) over 12 square degrees. The SZE has the remarkable property that it is essentially redshift independent. Therefore the SZA will find all clusters above the survey mass-limit, independent of redshift. As the abundance of clusters with redshift is strongly dependent on the cosmology, the survey yields will be used to set tight constraints on cosmological parameters. The survey will be done using the 26-36 GHz band. The 85 - 115 GHz band will be used to perform detailed follow up observations of the survey detected clusters. These observations will allow an understanding of cluster structure evolution and its effect on using high-redshift clusters for cosmological studies.

The SZA will also be used as a compact sub-array of CARMA creating a unique and powerful heterogenous array, and thereby greatly increasing its angular dynamic range. (www.mmarray.org/)