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[S0002-7537(93)01231-4]

This report covers the period from 1999 April 01 through 2000 March 31, while the publications are for the calendar year 1999.

The James Clerk Maxwell Telescope (JCMT) Group of the Herzberg Institute of Astrophysics (HIA) supports the JCMT by supplying staff members to the Joint Astronomy Centre (JAC) in Hilo, Hawaii to help operate and maintain the telescope, by providing services, advice, and liaison to Canadian university astronomers, by building advanced receiver systems, and by serving on pertinent committees. Canada has a 25% share in the telescope, while the UK has 55% and the Netherlands has 20%. The three partner countries have access to 90% of the net observing time, according to their respective shares in the telescope, and the University of Hawaii has a 10% share. The international community also obtains observing time each semester through a peer-reviewed competition that is similar to that held by the partner countries.

1. PERSONNEL

The JCMT Group staff includes L. W. Avery (Group Leader), S. M. X. Claude, C. T. Cunningham, P. A. Feldman, H. E. Matthews (JAC), A. Mirza, G. H. Moriarty-Schieven (JAC), R. O. Redman, G. X. Rodrigues (since 2000 January), and K. K. Yeung. M. B. Bell, T. H. Legg, and J. M. MacLeod are Guest Workers. In addition, HIA funds three staff positions at the Joint Astronomy Centre as well as Canada's share of the telescope operations and instrument development. Maryanne Kelly and Jesse Eyer, Coop students from U. Victoria, worked with K. K. Yeung and G. H. Moriarty-Schieven, respectively. R. Singh worked with C. T. Cunningham for 7 months from 1999 April 1 before taking a permanent position at Nortel Networks.

2. SCIENTIFIC RESEARCH

2.1 Solar System

Several programs by Redman, Feldman, and Matthews to study thermal continuum emission from asteroids were severely hampered by bad weather, instrument problems, and even telescope failure over the last year. On a brighter note, recent observations of Ceres and Pallas with the SCUBA polarimeter by Redman, Lagerros (Uppsala), and Matthews appear to have been successful. These data are undergoing final reduction in preparation for publication.

Moriarty-Schieven began a collaboration with B. J. Sandor (NCAR) and R. T. Clancy (SSI, Boulder) to obtain JCMT observations of CO and its isotopomers toward Venus in order to understand the temperature and chemistry above the Venusian cloud tops. Observations in 1999 were used to measure possible diurnal variations in water-vapor abundance in the lower mesosphere of the planet. These observations also showed that a dramatic cooling of the upper atmosphere of Venus began between June and July of 1999.

Matthews collaborated with A. Marten (Meudon), T. C. Owen (IfA), and R. Moreno (IRAM) to make JCMT spectral observations of Saturn's large moon Titan which have yielded a detection of the $C^{18}0$ (3-2) transition. These data are being used to model the atmosphere of the satellite.

2.2 Interstellar and Circumstellar Matter

Bell, with Avery, E. R. Seaquist (U. Toronto) and J. P. Vallée (HIA), continued their analysis of impact broadening in high-Δ n recombination lines of hydrogen by generating impact-broadened Voigt profiles and inserting them into data files from the NRAO 140-ft telescope so that the effects of data processing could be measured and corrected. The new analysis finds significantly higher densities than were derived previously with similar beam sizes. This approach has also shown that the observed linewidth variations at high-Δ n are not artifacts of the data-reduction program. They conclude that these variations, which are contrary to what is predicted by Griem's theory, originate in the high-density gas.

Bell has found from observations of the 8.665 GHz hyperfine spin-flip transition of $^3He^+$ in eight Galactic H II regions that second generation $^3He^+$ decreases rapidly with distance from the Galactic Center and falls below detectable levels by the Galactic distance of W49 $\sim$ 8 kpc. This is contrary to what has been found by others. Previously reported detections in the outer Galaxy appear to be due to weak terrestrial interference. The upper limit obtained for primordial $^3He^+$ is an order of magnitude below previous estimates (see Bell, M. B. 2000, ApJ, 531, 820).

Redman and Feldman, together with S. J. Carey (Boston College) and M. P. Egan (AFRL), used the JCMT in 1999 April and September to make SCUBA and heterodyne observations of dust and molecular gas, respectively, towards MSX Infrared-Dark Clouds (IRDCs). The IRDCs are very large, often elongated molecular cloud cores with H_2 gas densities $\sim 10^6$ cm^{-3}, temperatures about 15 K, and H_2 column densities ranging up to 10^{23} cm^{-3}. The IRDCs are observed to have prominent filamentary structures, especially in dust emission. The continuum radiation from these regions exhibits strong linear polarization, indicating the presence of well-ordered magnetic fields. Compact, bright cores in various early stages of star formation are found along the filaments. There is reason to believe that the IRDCs may be sites of high-mass star formation. A synoptic paper is in press in the Proceedings of the 33rd ESLAB Symposium, ''Star Formation from the Small to the Large Scale.'' Another paper is in press at ApJ Letters and several others are in preparation. Observing time on the JCMT has been granted in Semester 00A for further SCUBA polarimetry.

Feldman and Redman, together with D. D. Balam (U. Victoria) and S. J. Carey (Boston College), used the 1.8-m Plaskett telescope at the DAO to search for shock-excited gas associated with the compact submillimeter sources which are found to be embedded in MSX Infrared-Dark Clouds. Optical observations of G79.3+0.3 have revealed at least one Herbig-Haro jet that appears to originate from a deeply embedded T-Tauri-like star in the vicinity. Further work is in progress.

Matthews, W. H. McCutcheon (UBC), and G. J White (QMW, London) are using SCUBA 850/450 μm images of the entire chain of star-forming regions connected with the galactic nebula NGC 6334, together with previously obtained maps of CO emission and other archival data, to model the region. The five well-known, dense, ionized-hydrogen/IR cores appear to be connected with a bright, curved, and essentially unresolved filament of dust emission, which may be associated physically with the formation of the young stellar clusters. C. R. Purton (HIA) and Matthews have almost completed their analysis of the complex data cubes obtained from a DRAO synthesis observation of the NGC 7129 star-forming core in the 21-cm neutral-hydrogen line. A new (and only the second known) dissociating star has been recovered from these data; this object has a dynamical age of only 10^3 years.

Avery, Matthews, and Moriarty-Schieven continue as part of the Canadian team studying a number of star-forming regions with the help of dust emission images and associated molecular observations using the JCMT. The goal is to obtain extended and sensitive submillimeter images with high dynamic-range in order to conduct comparative studies of regions exhibiting different star-forming properties. Continuum and spectral-line observations of large fields in the ρ Ophiuchi cloud are complete. D. I. Johnstone (CITA) and C. D. Wilson (McMaster) have led an analysis of the mass function of 55 submillimeter condensations in this star-forming region. Work has continued with both CO (2-1) and SCUBA mapping of extensive regions in the Orion B complex. Polarimetric images at 850 μm of the brightest peaks in these regions were also obtained. This team held a workshop at DAO in May 1999 to discuss the data, science issues, and future work. One paper is in press at ApJ and a number of others are in preparation.

D. I. Johnston (U. Toronto), C. D. Wilson (McMaster U.), Moriarty-Schieven, J. Giannakopoulou-Creighton (IPAC) and E. Gregersen (McMaster U.), part of the Canadian star-formation consortium, completed an analysis of several methods of reconstructing images using the scan-map technique for mapping large areas of sky with the SCUBA bolometer camera on the JCMT. The Emerson Fourier restoration technique commonly used at the JCMT was both efficient and quick, but was found to be inferior to a matrix-inversion technique, especially where there is structure near the edges of the mapped region or where the noise is not constant over the map. A paper on these results is in press at ApJ.

Moriarty-Schieven also worked with H. M. Butner (SMTO) and J. A. Powers (U. Hawaii, Hilo) on the modeling of circumstellar disks around young protostars in Taurus, and on signatures of protostellar envelope collapse with G. Narayanan (FCRAO).

Feldman and Redman, in collaboration with HIA colleagues T. J. Davidge, P. B. Stetson and J. E. Hesser, are investigating the possibility that metal-rich globular clusters contain detectable quantities of cool dust and some possible ways that the presence of such dust might correlate with cluster properties. They have been awarded JCMT observing time in Semester 00A to use SCUBA for a pilot program.

Claude, Avery, and Matthews have observed SO and SO_2 emission lines having a wide range of excitation energy in the protoplanetary nebula OH231.8+4.2 (Rotten Egg Nebula). The extent of the SO emission was mapped and the rotation temperatures of SO and SO_2, together with the column densities of the two molecules, were deduced. The abundances of SO and SO_2 relative to H_2 in the outflow lobes are found to be enhanced, consistent with the predictions of shock chemistry. In recent CANSERV follow-up observations of the north outflow lobe of OH231.8+4.2, weak lines of methanol and SiO were detected.

2.3 Extragalactic Astrophysics

Moriarty-Schieven, D. A. Frail (NRAO), S. Kulkarni (Caltech) and others continued their JCMT study of submillimeter emission from gamma ray bursters (GRBs), as part of a larger study of the radio, infrared, and optical transients that follow the X-ray or gamma-ray emission of GRBs. Two GRBs were observed with SCUBA during 1999, GRB990123 (Kulkarni *et al.* 1999, ApJ, 522, L97) and GRB991216 (Frail *et al.* 2000, submitted to ApJ), but neither was detected at submillimeter wavelengths. These observations have placed important constraints on parameters of the forward and reverse shocks in the fireball model for GRBs.

Analysis of the SCUBA images obtained at 850 and 450 μm of the dust distribution over the central 10 arcmin of the active galaxy Centaurus A by Matthews, with L. L. Leeuw and E. I. Robson (JAC), A. Eckart and L. Tacconi (MPI-Garching), and T. G. Hawarden (JAC), is now almost complete. These data show very clearly the twisted disk at the core of this famous object.

3. INSTRUMENT DEVELOPMENT

3.1 JCMT Receiver Upgrades and Mixer Development

Cunningham developed a new mixer design to upgrade the devices that had been delivered with JCMT Receiver B3. The objective was to eliminate the need for a mechanically tunable backshort while retaining the low-noise and wide-band performance. Both mixers have now been replaced with tunerless versions having the same or better performance for all of the commonly used frequencies. The 345 GHz receiver now has improved efficiency and reliability.

Claude built and tested seven tunerless mixers for JCMT Receiver A3 using super-conducting chips supplied by NRAO, but none met the performance requirements due to problems with device uniformity. No further devices are available and this effort is currently on hold. However, Claude and Cunningham replaced the multiplier for A3 with

a tunerless version and replaced the cryostat with a newer one available at the JCMT in order to improve the hold time.

Claude produced a matched pair of 250 GHz mixers for the ALMA Evaluation Receivers in close collaboration with NRAO. The mixers, which were delivered in early January 2000, exhibited state-of-the-art performance across the required RF band. A spare mixer has also been built but will not be delivered immediately because its performance can be improved.

Claude started the development of balanced, sideband-separating, 250 GHz mixers for the ALMA receivers using Microstripes software for 3-dimensional waveguide design. He has been successful in designing a 3-dB hybrid coupler which is the main component in such a mixer. The design is a compromise between meeting the electrical requirements and the limitations imposed by CNC machining. These results have been summarized in JCMT Group Technical Report 1999-1. Claude has also performed transmission-line modeling of waveguide components for this type of mixer. The components analyzed include a 3-dB branch-line coupler, a Y-junction power splitter, and bends. This mixer development is a key element in the potential Canadian technical involvement in the ALMA project.

3.2 Spare Electronics Modules for JCMT Receiver B3

Yeung tested, repaired, and debugged the spare electronics modules for the 345 GHz receiver. A complete set of up-to-date schematic diagrams of all the electronics modules for this receiver was delivered to JAC in the summer of 1999.

3.3 The JCMT ACSIS Correlator

The development of the ACSIS IF System for the new ACSIS correlator is a joint collaborative project involving Yeung with W. Dent (UKATC) and B. Force (JAC). The role of the ACSIS IF System is to subdivide and down convert each IF input from the B-band heterodyne array receiver into two separate 0-1.0 GHz base-band signals. These signals are then fed into the correlator section to produce the normalized auto-correlation results. The hardware and software designs of the IF controller were completed by Yeung, with the assistance of co-op student Maryanne Kelly, for the successful Interim Design Review (IDR) in 1999 June. A prototype of the ACSIS IF system, which is based on the design descriptions given in the IDR documents, is currently being constructed at DRAO.

3.4 The JCMT HARP-B Heterodyne Array Receiver

The JCMT's Heterodyne Array Receiver Program (HARP) has begun the design and construction of a 16-detector B-band (345 GHz) array receiver for the JCMT under the leadership of MRAO. Redman and Yeung participated in the successful HARP-B Conceptual Design Review in 1999 March. Redman is acting as the lead for the software design and development in the project. He has prepared a preliminary description of a generic HARP receiver which will be used to develop a control system that can be customized to the actual HARP-B receiver hardware after the Preliminary Design Review later in 2000. The control software itself will be written in EPICS, an operating system layered over VxWorks for the development of real-time control systems. Yeung, who is responsible for the design and implementation of the LO chain and the microcomputer system for the HARP receiver, has prepared a conceptual design of the LO chain. The complete LO subsystem is scheduled to be delivered to MRAO in 2001 December.

3.5 Water Vapor Monitors

Interferometric observations at frequencies above 200 GHz require that the measured phase be corrected for the effects of fluctuations in the column density of water vapor along each telescope's line-of-sight. This information would increase the coherence times, thereby enabling arrays to better achieve their designed sensitivity and spatial resolution. Two different approaches to provide a practical solution for this problem are being investigated by the Group.

Feldman is collaborating with D. A. Naylor at the University of Lethbridge to use atmospheric infrared emission lines to monitor changes in the column density of water vapor along the line of sight. A test water-vapor monitor has been constructed at Lethbridge using fast HgCdTe photoconductive detectors to measure telluric water lines in the mid-infrared region. These lines were chosen to provide reliable estimates of the column density of water under conditions of good atmospheric transmission, using a detailed model of the atmosphere above Mauna Kea. Initial testing of this instrument on Mauna Kea in 1999 December showed that the IR technique is at least as good in monitoring water vapor changes as the 183 GHz system now in place at the JCMT.

Cunningham is collaborating with C. D. Wilson (McMaster), P. E. Dewdney (HIA), and A. R. Taylor (U. Calgary) on the construction of a 183 GHz radiometer similar to the one designed by MRAO for the JCMT-CSO interferometer. Singh was recruited for the project and worked on it for seven months after 1999 April. After he left for a permanent position, Rodrigues replaced him in 2000 January. This work is expected to be completed by the summer of 2000. The 183 GHz radiometer is intended for linking the JCMT with the Smithsonian Submillimeter Array. Longer-term goals center on a technical comparison of the two technologies (millimeter and infrared) to determine the relative advantages of each for phase correction.

3.6 Planar Arrays

Legg and Bell continued work on a submillimeter wavelength heterodyne planar array, a collaborative program comprising NRC, the University of Alberta, and the Alberta Microelectronics Corporation (AMC). New SIS junctions were received from AMC in 1999 April. Two of these devices have the longest lives so far encountered, have survived many experiments, and exhibit I-V characteristics that are almost unchanged after 10 months. The junctions were used largely in beam-pattern measurements. Clean beam patterns with very low side-lobes, in agreement with theoretical calculations, were found at most, but not all, frequencies. Two beams were measured from antenna-mixers that were

placed side-by-side, demonstrating that the current antenna-mixers could be combined successfully into a single array.

4. FUTURE OF CANADIAN RADIO ASTRONOMY

4.1 Atacama Large Millimeter Array (ALMA)

Following the strong recommendation by the Long-Range Planning Panel (LRPP) that Canada should become involved in ALMA, the JCMT Group has begun a collaboration with the U.S. National Radio Astronomy Observatory, in anticipation that a formal North American partnership will be negotiated. Although resources are currently limited, the long-term goal is to contribute to Canadian intellectual involvement in ALMA through development work that will lead to the next generation of submillimeter receivers. As the first step the Group has delivered state-of-the-art mixers to NRAO for incorporation into the 230 GHz receivers that will be built for the ALMA evaluation antennas. Current plans call for the JCMT Group to work with their NRAO colleagues to develop innovative mixer designs and prototypes that would provide excellent performance and reliability. These mixers also have to be suitable for relatively rapid production, given that over one hundred receivers will be required for each observing band. Cunningham serves on the joint US/European receiver development group for ALMA.

4.2 Square Kilometre Array

Legg is continuing to work on concepts for the design of a Large Adaptive Reflector as a component of the proposed Square Kilometer Array (SKA). This work includes a design for a Fresnel surface to facilitate observations at low frequencies and a scheme for a rapidly adjustable feed system.

5. JCMT SUPPORT

5.1 CTAG and PATT

Matthews served as a member of the Canadian Time Allocation Group (CTAG) in Semesters 99A and 99B. Beginning with Semester 00A he became chair of CTAG and also served as the CTAG representative on the International Time Allocation Committee (ITAC), part of the United Kingdom Panel for the Allocation of Telescope Time (PATT).

5.2 JCMT Advisory Panel

Redman continues to serve as one of the two Canadian representatives on the JCMT Advisory Panel.

5.3 Canadian Service Observing (CANSERV)

Feldman continued to act as CANSERV coordinator. As in the past, CTAG members serve as referees (two for each proposal). Matthews and Moriarty-Schieven provide the technical assessments.

Canadian JCMT support scientists (Matthews and Moriarty-Schieven) and other experienced astronomers from the Group in Victoria carry out short observing programs on the JCMT for Canadian astronomers so that they do not have to travel to the telescope to acquire small amounts of data (generally four hours or less). Such observations are useful in responding rapidly to new astronomical discoveries, accommodating important short observations, monitoring variable objects, completing nearly finished projects, or providing pilot or speculative observations prior to a full application for observing time. CANSERV observations were performed for the following 13 projects during JCMT Semesters 99A and 99B (1999 February 1 to 2000 January 31):

- Locations of Galactic Molecular Clouds (Petitpas and Wilson, McMaster U.)
- The Wind of Cyg OB2 No 5 (Dougherty, HIA)
- Polarized radiation and the Interstellar Magnetic Field (Brown and Taylor, U. Calgary)
- Mapping C I in NGC 604 (Wilson and Taylor, McMaster U.)
- A Search for Interstellar Protonated Acetylene (Matthews; Oka and McCall, U. Chicago)
- Excitation Analysis of SO in OH231.8 (Claude, Cunningham, Avery, Matthews, and Yeung)
- Mapping OH231.8 in SO (Claude, Cunningham, Avery, Matthews, and Yeung)
- Searching for the Exciting Source of the Spectacular V380 Ori-NE CO (4-3) Outflow (Matthews; Davis, JAC)
- CO and HCN in the Molecular Envelopes of New 21 μ Sources (Kwok, U. Calgary; Hrivnak, Valparaiso U.)
- HCO^+ in G81.50 P1 and P2 (Redman and Feldman; Carey, Boston College; Egan, AFRL)
- Interacting Galaxies and Galaxy Evolution at Intermediate Redshifts (Pritchet, U. Victoria; Carlberg, U. Toronto; Patton, U. Victoria; Morris, HIA; Gower, U. Victoria; Hall, U. Toronto)
- Probing Shock Enhanced Chemistry in the North Outflow of OH231.8+4.2 (Claude, Avery, and Matthews)
- CO in Shells Around R Coronae Borealis Stars: Old Planetary Nebulae? (Feldman; Clayton, LSU)

6. PUBLICATIONS

6.1 JCMT Group Publications (Calendar Year 1999)

Bell, M. B., Feldman, P. A., Watson, J. K. G., McCarthy, M. C., Travers, M. J., Gottlieb, C. A., & Thaddeus, P. 1999, Observations of Long C_nH Molecules in the Dust Cloud TMC-1, ApJ, 518, 740

Biver, N., Bockelée-Morvan, D., Crovisier, J., Davies, J. K., Matthews, H. E., Wink, J. E., Rauer, H., Colom, P., Dent, W. R. F., Despois, D., Moreno, R., Paubert, G., Jewitt, D., & Senay, M. 1999, Spectroscopic Monitoring of Comet C/1996 B2 (Hyakutake) with the JCMT and IRAM Radio Telescopes, AJ, 118, 1850

Davis, C. J., Matthews, H. E., Ray, T. P., Dent, W. R. F., & Richer, J. S. 1999, A Burst of Outflows from the Serpens Cloud Core: Wide-Field Submillimetre Continuum, CO J = 2-1 and Optical Observations, MNRAS, 309, 141

Jewitt, D. C., & Matthews, H. E. 1999, Particulate Mass Loss from Comet Hale-Bopp, AJ, 117, 1056

Kulkarni, S. R., Frail, D. A., Sari, R., Moriarty-Schieven, G. H., Shepherd, D. S., Udomprasert, P., Readhead, A. C. S., Bloom, J. S., Feroci, M., & Costa, E. 1999, Discovery of a Radio Flare from GRB 990123, ApJ, 522, L97

Sandell, G., Avery, L. W., Baas, F., Coulson, I., Dent, W. R. F., Friberg, P., Gear, W. P. K., Greaves, J., Holland, W.,

Jenness, T., Jewell, P., Lightfoot, J., Matthews, H. E., Moriarty-Schieven, G. H., Prestage, R., Robson, E. I., Stevens, J., Tilanus, R. P. J., & Watt, G. D. 1999, A Jet-Driven, Extreme High-Velocity Outflow Powered by a Cold, Luminosity Protostar near NGC2023, ApJ, 519, 236

Taylor, A. R., Irwin, J. A., Matthews, H. E., & Heyer, M. H. 1999, JCMT Observations of Cometary Clouds in the Galactic Chimney near W4, ApJ, 513, 339

White, G. J., Nelson, R. P., Holland, W. S., Robson, E. I., Greaves, J. S., McCaughrean, M. J., Pilbratt, G. L., Balser, D. S., Oka, T., Sakamoto, S., Hasegawa, T., McCutcheon, W. H., Matthews, H. E., Fridlund, C. V. M., Tothill, N. F. H., Huldtgren, M., & Deane, J. R. 1999, The Eagle Nebula's Fingers - Pointers to the Earliest Stages of Star Formation?, A & A, 342, 233

Wilson, C. D., Avery, L. W., Fich, M., Johnstone, D., Joncas, G., Knee, L. B. G., Matthews, H. E., Mitchell, G. F., Moriarty-Schieven, G. H., & Pudritz, R. E. 1999, Submillimeter Continuum Emission in the ρ Ophiuchi Molecular Cloud: Filaments, Arcs, and an Unidentified Far-Infrared Object, ApJ, 513, L139

6.2 JCMT Group Technical Reports (Calendar Year 1999)

Claude, S. M. X. 1999, Development of a Waveguide 3-dB Hybrid Branch-Line Coupler for ALMA, JCMT Group Technical Report No. 1999-6, Herzberg Institute of Astrophysics

Dent, W., Duncan, W., Harris, J., Hastings, P., Hills, R., Richer, J., Withington, S., Smith, H., Gibson, H., Avery, L., Redman, R., & Yeung, K. 1999, Heterodyne Array Receiver HARP-B: B-Band Camera and Fore Optics, JCMT Group Technical Report No. 1999-1, Herzberg Institute of Astrophysics

Dent, W., Redman, R. O., Yeung, K., & Hovey, G. 1999, Coordination of Subsystems through the RTS, JCMT Group Technical Report No. 1999-2, Herzberg Institute of Astrophysics

Matthews, H. E., 1999, The James Clerk Maxwell Telescope: a Guide for the Prospective User, JAC Internal Technical Report, Joint Astronomy Centre

Yeung, K., Dent, W., & Force, B. 1999, ACSIS IF System Hardware Design, JCMT Group Technical Report No. 1999-4, Herzberg Institute of Astrophysics

Yeung, K., & Kelly, M. 1999, ACSIS IF System Software Design, JCMT Group Technical Report No.1999-5, Herzberg Institute of Astrophysics

6.3 Publications By Visitors Using Allocated Canadian JCMT Time (Calendar Year 1999)

Refereed publications of JCMT observations reached a new annual high in 1999, with 82 having been identified as of 2000 March. Twenty-one of these have Canadians as P.I.s and/or co-authors. The publications by Canadian astronomers outside of HIA using data from the JCMT are listed in the annual reports of that facility.

Paul Feldman