National Research Council of Canada
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This report covers the activities of the JCMT Group for the period from 1995 April 1 to 1996 March 31. We are changing our reporting interval to coincide with our fiscal year. Since the last report covered November 1994 to mid-October 1995, we shall describe the scientific activities of the group for only the period from October 1995 to the end of March 1996.

The James Clerk Maxwell Telescope (JCMT) Group of the Herzberg Institute of Astrophysics (HIA) supports the JCMT by posting several staff members to 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 a 55% share and the Netherlands a 20% share. The three partner countries have access to 90% of the net observing time, according to their share in the telescope, and the University of Hawaii has a 10% share. The international community also obtains observing time each semester.

1. PERSONNEL

Astronomers and Engineers include L.W. Avery (Joint Astronomy Center (JAC), Hilo, from September 1995), M.B. Bell, C.T. Cunningham, P.A. Feldman, R.H. Hayward, T.H. Legg (until September 1995), J.M. MacLeod (Group Leader), H.E. Matthews (JAC), R.O. Redman, J.P. Vallée, and J.D. Wade. Technologists include C.R. Bergeron (until July 1995), S. Brooke (JAC), J.R. Fletcher (JAC until July 1995), A. Mirza and E. Taada (from August 1995). Guest workers include T.H. Legg (from October 1995), and J.P. Towle.

Women in Engineering and Science Students included Diane de Kerckhove (with Wade & Cunningham), Karima Kanji-Tajdin (with Redman, Feldman, and Wade), and Jessica Arlett (with Avery). M. Pollanen worked as a summer student with Feldman.

In addition, two staff at the Joint Astronomy Centre are supported by financial contributions from the National Research Council of Canada.

2. SOLAR SYSTEM RESEARCH

Feldman and Matthews in collaboration with McDade (York U.), Amano, (Ibaraki U., Japan), and Singleton and Kudo (IERT, NRC) used the JCMT to detect the $J=4-3$ line of $O_2(^1\Delta_g)$ in the Earth's atmosphere for the first time. With the help of Karima Kanji-Tajdin they used laboratory data to estimate the pressure broadening coefficient of $O_2(^1\Delta_g)$ itself in order to calculate the vertical density profile of this important species in the atmosphere. More recently, Amano and his student have made direct laboratory measurements at IMS (Okazaki) which support this revised estimate of the pressure broadening coefficient.

Redman, Feldman and Matthews have continued the study of thermal emission from asteroids. By combining data taken at millimeter and submillimeter wavelengths using the JCMT with thermal infrared data from the IRAS Minor Planet Survey, it has been found that the emissivities of M-type asteroids, whose mineral compositions are dominated by metallic iron, drop steadily from near unity in the thermal infrared to values near 0.25 at 1 mm wavelength. Asteroids with stony or carbonaceous compositions have much larger emissivities at 1 mm, ranging between 0.6 and 1.0. This is the first clear compositional signature found in the thermal emission of the minor planets.

Matthews (JAC), in collaboration with Marten and Gautier (Meudon), and Owen (IfA), has continued to obtain occasional observations of the stratosphere of Jupiter, chiefly using the HCN $J=4-3$ transition. These data, together with the earlier results (Marten *et al.*, 1995) provide a unique record of the evolution of this molecular layer in the aftermath of the collision of Shoemaker-Levy 9 with Jupiter in July 1994. Recent results show a spreading of the HCN haze in latitude away from its original impact latitude of -44deg. The longevity of HCN is thought to be due to shielding against photolysis by simple hydrocarbons in the upper Jovian stratosphere.

Matthews announced with Jewitt and Senay (IfA) in September 1995 the first detection of CO from the bright long-period comet Hale-Bopp, using the JCMT. CO is the first major volatile to be released from comets as they approach the Sun while still beyond the orbit of Jupiter, and is responsible for the development of the early coma. Since that time Matthews has continued a program in collaboration with Jewitt and Senay to monitor the molecular development (mainly CO and HCN) of Hale-Bopp, eventually through its perihelion passage in April 1997.

In the meantime, from February 1996, Matthews coordinated JCMT observations in the 345-GHz window of comet Hyakutake, which made a surprise visit to the inner solar system in March. Although Hyakutake was a fairly small comet, the closeness (about 0.1 a.u.) of its passage by the Earth resulted in some spectacular results, including the first detection of HNC in a comet (Irvine *et al.* 1996; Nature 313, 418), and the first submillimeter map of a comet (Jewitt, Matthews, in press). The former has significance for the constitution of the early solar system, and the latter demonstrates the presence of mm-size particles in the cometary coma. A large body of data, in particular of submillimeter lines of HCN, CO, CS, H_2CO, and CH_3OH was obtained, and is being analysed in collaboration with groups from UH Manoa, JAC, and Meudon.

3. STARS, PROTOSTARS, CIRCUMSTELLAR ENVELOPES, PROTOSTELLAR DISKS, STELLAR OUTFLOWS, POST-AGB STARS.

Avery & Chiao published the results of their study of the methanol enhancement in the L1157 outflow. This work continues with observations of other methanol-rich flows. These flows are being mapped with the JCMT in the $5_{1/2}-4_{1/2}$ lines of methanol at 241.8 GHz, and submillimeter lines spanning a range of excitation energies are being used for statistical equilibrium analyses. Preliminary analysis of flows in NGC 2024B (FIR 6) and V380 Ori NE indicate kinetic temperatures of 60K and 100K repectively, and methanol abundances that are moderately enhanced relative to the values in dark clouds. These sources are both cooler and show smaller methanol abundances than L1157.

Avery & MacLeod discovered strong methanol emission in the V380 Ori NE outflow which they mapped in methanol, SO and CS lines with the JCMT. These maps revealed clearly that the source of the outflow was not IRAS 0534-0639, as suggested in the literature. Continuum observations with the JCMT have revealed a new source centrally located between the V380 outflow lobes that does not appear as an IRAS source. It is a good candidate for a new Class 0 object. With Aspin, Avery & MacLeod obtained UKIRT images at 2.12μm of shocked H_2 gas in both the red and blue lobes of this flow. Work is continuing on observations of the shock-excited H_2 emission associated with these methanol-rich sources to investigate the relationships between the chemical enhancements and shock activity.

Avery & Arlett (Queen's University, Kingston) developed statistical equilibrium codes for CO and SO molecular line analysis covering lines of high excitation for application to shock-heated molecular gas in outflows. Application of the SO code to multi-line observations of 6 compact flows are consistent with high kinetic temperatures of around 200K with a tendency for the H_2 densities to be bi-model. Some sources are fit best by values around $10^4 cm^{-3}$, others by values around $10^6 cm^{-3}$. Work will continue to improve the modelling and acquire additional data to test the reality of these preliminary conclusions. Avery & MacLeod are collaborating in a search for a number of ground-state transitions from molecules in extragalactic sources. These include molecules such as NH_3, H_2O and H_2S, with lowest-level line frequencies that are not accessible from the ground. However, in extragalactic sources, they are red-shifted into the bands accessible to the JCMT. To date the $1(0)-0(0)$ line of NH_3 with a rest frequency of 572 GHz has been sought in PKS 1830. Work is continuing on other molecular lines.

Following up on the work mentioned in the last report to the BAAS, Feldman & Geballe (UKIRT, JAC) have detected a fourth sulfur-bearing molecule in the vicinity of the unusual IR source W33A. This work gives further credence to the hypothesis that several of the unidentified IR absorption features seen towards this star may be due to vibrational transitions of simple sulfurated molecules frozen on the surfaces of grains along the line of sight to the star.

Observations were made using the JCMT-CSO interferometer at 354 GHz of the H26α recombination line from MWC 349 by Thum (IRAM), Morris (UCLA), Matthews (JAC), Hills, (Cambridge), Carlstrom and Lay (OVRO). The results, currently being analysed, show that the maser spots do indeed inhabit the inside edges of a circumstellar disk in Keplerian rotation about the central massive star. A paper is in preparation. In collaboration with Clemens and Thum (IRAM), ISO observations of infrared recombination lines toward MWC 349 have been obtained, which show that the masing continues into this regime.

4. INTERSTELLAR MATTER AND MAGNETIC FIELDS IN THE GALAXY

Feldman, Pollanen (Carleton U.) and Galt (DRAO), continued the study of the methanol masers they had previous found in star-forming regions using the DRAO 26-m telescope. The JCMT was used to detect HCO^+ $J=4-3$ and/or $J=3-2$ towards all of the maser sources, indicating that they are associated with dense cloud cores with $n(H_2)>10^6 cm^{-3}$. In collaboration with Moriarty-Schieven (JAC, Hilo) they found that the methanol maser associated with the S233 outflow appears to originate from the vicinity of the tip of one of the bipolar outflow lobes. Methanol and other molecules are believed to be liberated from ambient grains in the shocks associated with some outflows.

The raster technique has been put to use in the mapping of two large fields covering the major star-forming regions NGC 6334 and M8. This work is being done by McCutcheon (UBC), White (QMW) and Matthews. The main goals of this work are (1) to determine the dust-gas ratio over those parts of the field which have already been mapped in submm continuum radiation, and (2) to investigate the inter-isotopomeric ratios of ^{12}CO, ^{13}CO, $C^{18}O$, and $C^{17}O$ as a function of cloud age and other parameters. This work is in the process of data reduction. An interesting by-product is the recognition of filamentary molecular structures on scales approaching that of the entire cloud.

Large-scale mapping of CO $J=2-1$ has been used by Matthews in collaboration with Taylor (U. Calgary), Irwin (Queen's U.) and Heyer (U. Mass.) to study two fields in the W4 region, specifically to investigate the molecular component of the ISM in the region of a galactic ''chimney,'' for comparison with the observations of H I by the DRAO in the same region. These data show a classical case of the ablation of a molecular globule by a strong wind from a cluster of hot stars.

Matthews, with Purton (DRAO) and Mitchell (St. Marys U.) obtained neutral hydrogen observations of one of these regions (NGC 7129) with the DRAO, which will form the basis of direct comparison between neutral and molecular gas. HEM visited DRAO in November 1995 to carry out the reduction of these data. A paper is currently in preparation discussing features of the NGC 7129 region, in particular H I in the molecular cavity and surrounding the entire star-forming molecular cloud.

Vallée and Bastien observed the magnetic field in the molecular cloud M17-SW, with the JCMT at the extreme-infrared wavelength of 800 μm. They estimated the magnetic field strength to be around 300 μG, and they found the magnetic field shape to be mostly perpendicular to the cloud elongation, near the cloud ridge. They also created a new classification of 11 magnetic field types, according to two physical parameters: field shape, and field scale (pc). They then found that two of these 11 magnetic field classes could satisfy the observed data on M17-SW, and suggested that deeper observations in between the peaks in the cloud ridge could separate between the two classes.

What is the proper pitch angle p of the spiral arms of the Milky Way and how many spiral arms m are there? Vallée presented new analyses of the observational data, using for the first time magnetic field data in such studies. He found that the statistics indicated for the Milky Way a pitch angle $p \approx 12$deg, that the number of spiral arms $m \approx 4$, and that the flocculent model could not be applied to the Milky Way.

When it comes to the magnetic field in the Milky Way on a large scale, our position in the galactic disk hinders our attempts at interpreting the observational data, making the proposition of ''cherchez le champ magnétique'' a difficult one to follow. Vallée argued that magnetic field reversals in the Milky Way are crucial to all interpretations. He compared the two main interpretations, axisymmetric and bisymmetric azimuthal magnetic fields, and showed that the axisymmetric global magnetic field shape provides a better interpretation of the observational data in the Milky Way.

Vallée studied possible variations of the magnetic field strength B with gas density n. He found a statistically significant difference between the behaviour at low gas densities $n < 100\text{cm}^{-3}$, where $B \propto n^{0.2}$, versus large gas densities $n > 100\text{cm}^{-3}$ where it is known that $B \propto n^{0.5}$. Also, Vallée found that at low gas density values the galactic star formation rate $SFR \propto n^{1.3}$.

Vallée commented on the evolution since 1992 of our insights into the strengths and shapes of the magnetic fields of galaxies. Equipartition magnetic field strengths seem to be the norm in nearby spiral galaxies. Cosmic-ray-driven dynamo models seem to be gaining favour for spiral galaxies with an axisymmetric azimuthal magnetic field shape, while tidally-driven dynamo models seem to be accepted as the best way to produce a bisymmetric azimuthal magnetic field shape.

Vallée pursued the evidence for a link or a bond between galactic dynamos and galactic dynamics, as evidenced by the magnetic field shape of a spiral galaxy. He found that a more complex neutral hydrogen H I distribution or shape (possibly due to galactic encounter dynamics) goes along with a more complex azimuthal magnetic field shape (possibly due to excited dynamo states).

5. CANADIAN TIME ALLOCATION GROUP (C-TAG) FOR THE JCMT

The C-TAG Committee oversees the refereeing and assessment of proposals requesting time allocation for Canada's share on the JCMT. W. McCutcheon, UBC, Vancouver, is Chair. Feldman is a member of the C-TAG (since September 1992) and Chair of the JCMT International Time Assignment Committee. Vallée serves as Technical Secretary of the C-TAG. Other members are T. Hasegawa (St.Mary's, Halifax), Lloyd Higgs (DRAO, Penticton, since August 1995), and D. Puche (Montréal, since August 1995).

6. CANADIAN SERVICE OBSERVING (CANSERV) AT THE JCMT

Canadian JCMT support scientists and other experienced HIA astronomers from Ottawa carry out short observing programmes 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 projects during the period April 1, 1995 to March 31, 1996:

Physical Properties of Molecular Gas in Flocculent Spiral Galaxies (Wilson, McMaster U;. Thornley, U. Maryland)

HCO+(3-2) Observations of Two Methanol Masers in Star-forming Regions (Pollanen, Carleton U.; Feldman; Galt, DRAO)

The first submillimeter continuum spectrum of Ceres (Redman, Feldman, Matthews)

CO and CH_3OH lines in L1157 (Avery)

Compact Clouds in Cygnus X (Hughes, Queen's U -Kingston)

Investigation of a Galactic Chimney above W4 (Taylor, U. Calgary; Irwin, Queen's U.; Matthews)

The Structure of the Inner Circumstellar Shell Around IRC+10216 as Shown by CO $J=6-5$ (Matthews; Sahai, JPL; van der Veen, Columbia)

The Structure of the Inner Circumstellar Shell Around IRC+10216 as Shown by CO $J=4-3$ (Matthews; Sahai, JPL; van der Veen, Columbia)

Molecules in the Stratosphere of Jupiter (Matthews; Marten, Meudon; Owen, IfA-Honolulu)

Measurement of Mesospheric $O_2(^1\Delta_g)$ $J=4-3$ (McDade, York U.; Feldman; Matthews; Amano, Ibaraki U., Japan; Singleton, Kudo, Institute for Environmental Research and Technology, NRC)

Taking the Temperature of G35.2N (Matthews; Dent, JAC-Hilo)

Search for RRL Masers toward Ultra-Compact H II Regions (Feldman; Matthews; Strelnitski, New Mexico Inst. Tech-Socorro)

Photometric Observations of Protostar Candidates in IC5146 (Moriarty-Schieven, DRAO; Butner, Carnegie-Wash.; Lada, U. Maryland)

Search for Sulfur-Bearing Molecules Toward W33A (Feldman; Geballe, JAC-Hilo)

HCO^+ $J=4-3$ in M82 (Seaquist, U.Toronto; Bell)

Mapping Sulfur-Bearing Molecules toward W33A (Feldman; Geballe, JAC-Hilo)

HCN $J=4-3$ Emission from the IR Luminous galaxies NGC 3079 and NGC 3628 (Zhu, Seaquist, Frayer and Papadopoulos, U.Toronto)

Shock Chemistry in Outflows - the Effect on SO (Avery & MacLeod)

7. INSTRUMENTATION DEVELOPMENT

The JCMT Group is nearing the completion of a new 345 GHz receiver for the JCMT in Hawaii. This two-channel low noise SIS receiver is fully automatic and it is expected to provide a substantial improvement in observing speed over the current instrument. It will be commissioned on the telescope in December 1996.

In an attempt to maintain the best possible instrumentation on the telescope we are engaged in a receiver upgrade program. We are currently developing new SIS mixers for the 230 and 345 GHz bands. If they show promise they will replace the devices currently in use. We are also involved in developing a mixer for 800 GHz in collaboration with a group at the Rutherford Appleton Laboratory in the UK. In preparation for the linking of the JCMT to the Smithsonian array we will be modifying JCMT receivers by altering the intermediate frequency to match that of the array so as to maximize the overall array sensitivity.

The next major instrument to be built by the group will be a four-channel 230 GHz receiver. Again, this will offer a substantial improvement in observing speed when compared with the current single-channel instrument. It is expected that this project will start in 1997 and be commissioned in the year 2000

In the JCMT Planar Array Project, Legg and Bell, in collaboration with staff at the University of Alberta, continued development work on a heterodyne, focal-plane receiving array.

T. H. Legg has proposed a new type of radio telescope and is continuing to work on a some aspects of the design. The aim is to make very large telescopes more affordable. The telescope has a primary reflector that is ground-supported, almost flat, and slightly adjustable in shape. The feasibility of this type of instrument will be studied as a Canadian contribution to the international ''Square Kilometer Array'' project.

8. DATA PROCESSING, CONTROL SOFTWARE

Redman continued to develop the I-tasks (Instrument tasks) which will integrate the new B3 receiver into the JCMT telescope control system. Hayward continued to develop the real-time control software for the embedded OS-9/G-64 microcomputer used in Rx B3. De Kerckhove used LabView to develop an automated control and data acquisition system for performing beam-pattern measurements.

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