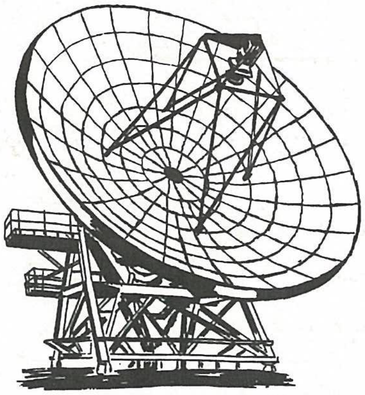

The JCMT Newsletter

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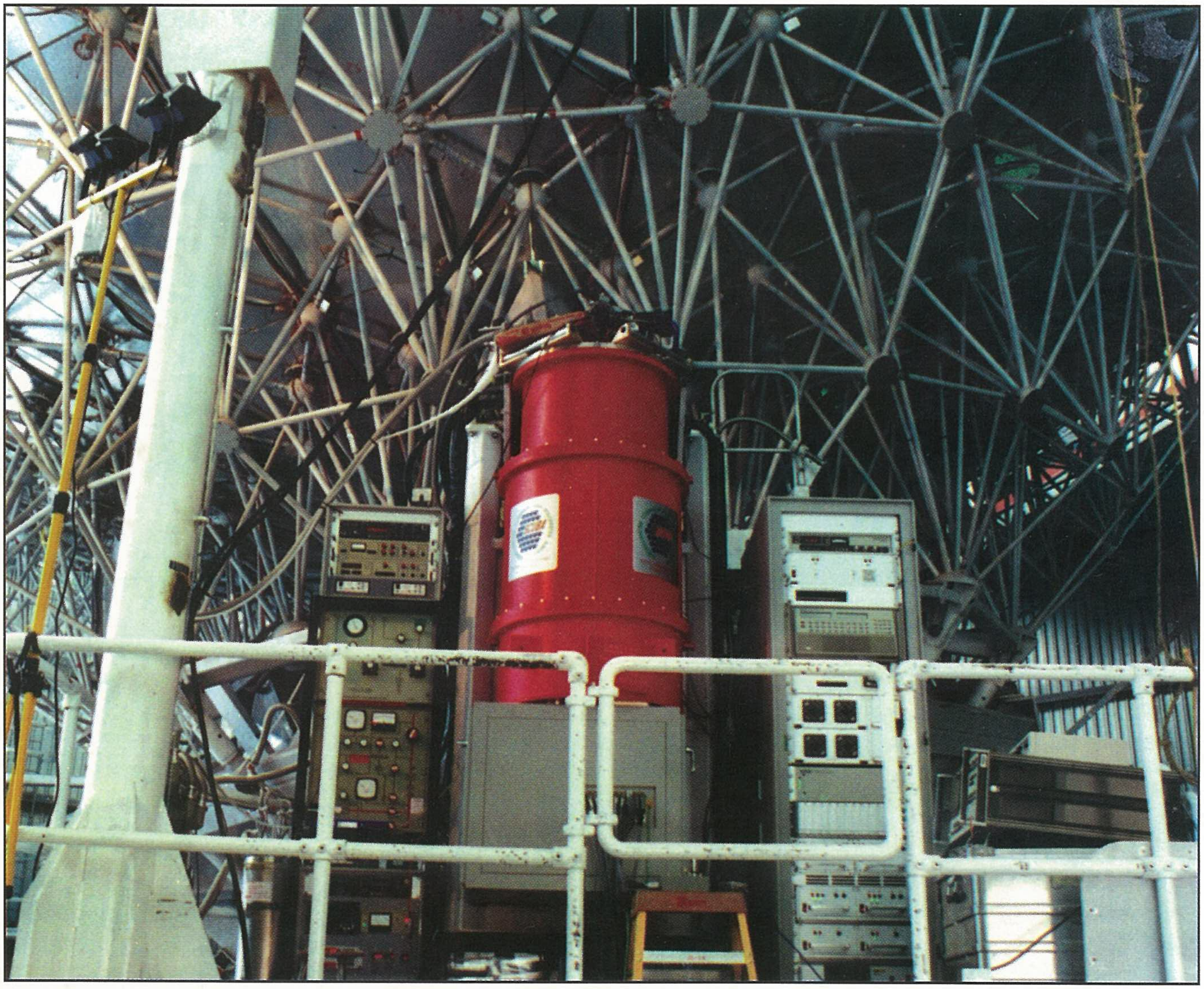

SCUBA is now on the JCMT!!!

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Front Cover: **The Submillimeter Common-User Bolometer Array (SCUBA) mounted on the JCMT Nasmyth.**

Back Cover: **An image of a star-forming region, W 48, observed at 850 microns with the SCUBA.**

Message from the Director

When I took up office as Director of the JCMT in Hilo in November 1992, SCUBA was scheduled to arrive the following semester. Well I'm delighted and relieved to say that it has finally arrived and indeed is the highlight of the semester. That isn't to say that all is going perfectly with the commissioning of SCUBA. There have been some setbacks, especially the inadequate filtering of the long-wavelength array, which to my mind is disappointing, only being discovered at the telescope. Furthermore, the weather has been far from co-operative and there have been some very frustrating times for the SCUBA team, trying to isolate weather problems from SCUBA unknowns — fortunately, most have been in the former category.

I have been particularly pleased and gratified by the extremely professional and efficient way the SCUBA team from ROE and the local staff have blended together to undertake the SCUBA assembly, installation and testing in Hilo and the subsequent assembly on the JCMT. This was an area that I had some concerns about in the light of commissioning some other major instruments and so I had required a high degree of planning to take place prior to the event. As it turned out, everything went extremely well. One of the main topics that the team need to focus on now (as well the actual commissioning) is the integration and training of the JCMT support astronomers in the SCUBA observing mode in preparation for the observations scheduled to commence at the end of the year.

I should also say that one of my big worries was that we would have endless software niggles, requiring ages to fathom out and significantly delaying the commissioning programme. I am delighted to say that while there have been the inevitable software bugs to fix, we are far better placed in this aspect than I had dared hope. Again, this is a tribute to both the ROE and local software staff supporting SCUBA. Nevertheless, the commissioning plan is undergoing constant modification in order to match the instrument, weather, and most-pressing problems requiring fixes. This has meant that we have not had the time to make many images which we could plaster over the cover of this Newsletter and on the Web. The actual observations of sources (apart from flat-fielding on the planets and 3C111) have been very sparse. As new observations become available in the testing phase, we will display them on the Web.

For those currently writing SCUBA proposals, do not worry, the SCUBA team will not be out scooping all those obvious sources in your lists and so it is with great enthusiasm I exhort you to get writing those proposals. Remember, although there is a maximum period of 24 hours there is no official minimum time-period. However, to help the referees, technical assessors and the TAG members in the limited time available to them, something like one-hour (including overheads) might be a target for you to consider (but this is just a personal view and the ITAC have set no ruling on this matter).

The length of time taken by the SCUBA project, and also RxB3 and RxW have been a matter of great concern to myself and the JCMT Board. We must get instruments onto the telescope more quickly, and Phil Jewell has proposed that the time from inception to commissioning for new instruments should be no more than three years. This has led us to consider the 'fast-track' concept, with receivers perhaps being delivered in stages — only the final stage having all the 'bells and whistles' of the current generation of 'observatory instruments'.

Plans for the development of the JCMT and its instrumentation are currently being worked up and members of the JCMT Advisory Panel will have these plans in early October, so that they can consult their user communities in time for the Panel meeting in early November and the Board two weeks later. At this Board meeting it is intended to identify and begin implementation of the ten-year development programme. We have an exciting tranche of developments to propose, and not surprisingly their total cost exceeds the funds available in the Development Fund to 2004. Therefore, some serious decisions will need to be made in November. These decisions will mould what instruments the JCMT will possess and how it might operate in the next century. Basically these decisions will shape how the JCMT takes its place in the future radio astronomical community.

In this light I should report that there has been development on the B-Band array front, or at least the new correlator proposed for it. Due to a very unfortunate piece of timing, we needed to purchase a raft of chips for the correlator before the final close-down of the line at the fabrication plant (or lose this opportunity). With the approval of the Board, this has now been done — and we will either be venturing down the road of chip speculation, or commencing on a new correlator — just one of the decisions to be made in November.

I need to close with an apology about the state of the current 230 GHz receiver (RxA2). I had expected that this would have been upgraded within the last six months as it was well known that (like UKT14) it was fast becoming life-expired and in need of major work. However, with the delay to the new receivers, the effort expected for the upgrade was not forthcoming and a series of interim measures were put in place. However, fate did not smile kindly on us and RxA2 finally gave up the ghost as far as being a useful instrument. This necessitated shipping it to RAL for repairs and upgrading with the installation of a new mixer from Tony Kerr. The history of this is described on the Web.

This brings me to my final point, the Web. The number and pace of changes taking place and the continued uncertainty of the delivery of the new instruments has amply shown that the timescale for notification of these time-critical information to the user-community is now incompatible with release in the paper-version of a Newsletter. From now on the Web will be the sole information medium for time-critical issues, especially those relevant to telescope applications. (Note that we also intend that the Newsletter will also appear on the Web). Therefore, this edition of the Newsletter marks a change, it now contains far more science and general news than information for writing observing proposals. Please help us in this by sending Graeme Watt interesting science articles resulting from your JCMT observations.

The future looks extremely bright with SCUBA now here and RxB3 and RxW to follow. I look forward to an exciting semester of new discovery.

Ian Robson,
Director, JCMT

The People Page

Steve Brooke returned to Canada at the end of June after nine years working as an Electronics Engineer for the JCMT.

Phil Moore returned to the UK in early July after a more than three years on the island as the JAC Chief Engineer.

Darrell DeCambra resigned his position at the JAC to take up a new job with Hawaii Electric Light Company.

Bill Reyes terminated his employment with the JAC in May and has started his own business.

Ken Laidlaw arrived in March from ROE to begin a three year tour as an Electronics Engineer with the JCMT.

Ian Smith also joined the JAC in March from ROE on a three year tour as a Software Engineer with the JCMT.

John Makuakane started at the JAC in May as a Mechanical Technician.

Rob Christiansen has been employed by the JAC as a receiver technician for the JCMT.

Colin Cunningham is at the JAC on a one year tour as the SCUBA Project Manager. He is responsible for overall planning and management of SCUBA installation and commissioning, as well as engineering support.

Walter Gear is also at the JAC on a one year tour as the SCUBA Project Scientist. He is responsible for astronomical commissioning of SCUBA and scientific output.

John Lightfoot is on a 6 month tour and is the designer and author of all the SCUBA observing software. He is responsible for its installation and testing, as well as training of JAC staff in its support.

Justin Greenhalgh arrived in late June to take on the position as JAC Chief Engineer. Justin is on secondment from the Rutherford Appleton Laboratory for three years.

Desiree Milar-Okinaka began work in August as the new Administration Clerk.

A variety of Canadian students are currently on short-period summer courses at the JAC:

Marco Pollanen is working with Henry Matthews.

Jessica Arlett is working with Lorne Avery.

Peter Yip is working with Richard McCarthy.

Steve Cockayne is working with Remo Tilanus.

Erin McPhalen is working with Ian Pain.

Congratulations to **Anna Lucas** and **Steve Hardash** on their marriage on 1st June. This is the first official JAC-Gemini link!

Congratulations to **Richard** and **Toni McCarthy** on the birth of a 'bouncing baby girl', **Beverly**, on 16th August weighing in at 8 lb 7 1/4 oz. Mom, Beverly and big sister Elizabeth are doing fine. We presume Dad is too!

NEXT ISSUE DEADLINE

The absolute deadline for submission of science and/or technical articles for the next issue of this Newsletter is **30th January 1997**. All communications regarding this Newsletter should be sent via e-mail to **gdw@jach.hawaii.edu**.

PATT Application Deadline

Deadlines for receipt of JCMT applications for semester 97A are:

for UK, Canadian, Netherlands and International applications:

30th November

Note the change of date and that **ALL** applications have the same deadline for this semester.

Note also that semester 97A contains only 5 months. It begins on March 1st 1997 and continues till July 31st.

To ensure prompt processing, please ensure that your applications are sent to the correct establishment. Applications for JCMT time should be submitted to the national TAG of the Principal Investigator (PI) or, if the PI is not from one of the 3 partners, to the national TAG of the first named co-investigator on the application who is from one of the partners. International applications (those with no applicants from one of the partners) should be submitted to the PATT Secretariat at PPARC, Swindon. Members of the JAC staff in Hawaii count as International unless they are the PI on an application, when it should be forwarded to the appropriate national TAG.

Country paying salary of Principal Investigator		
Canada	**Netherlands**	**UK or Other**
JCMT Time Allocation Group, Herzberg Institute of Astrophysics, 5071 West Saanich Road, Victoria, British Columbia, CANADA V8X 4M6	Dr. J. M. van der Hulst, Kapteyn Astronomical Institute, Postbus 800, NL-9700 AV Groningen, NETHERLANDS	PATT Secretariat, PPARC, Polaris House, Swindon, SN2 1ET, UNITED KINGDOM

Instrumentation Update

Web Access to JCMT Instrumentation Status

The current state of the JCMT instruments, their availability on the telescope and their sensitivities and other observational parameters can always be located on the JCMT home page of the World-Wide Web at URL:

http://www.jach.hawaii.edu/JCMT/home.html

Short Baseline Interferometry

It is anticipated that there will be an opportunity to participate in an SBI run during the Spring of 1997. The optimum period in which to arrange this 'block' of observations has not yet been decided. Further details on the availability of SBI will be found on the JCMT homepage, and via the e-mail exploder nearer the event.

Interested applicants are requested to submit their applications by the appropriate deadlines for either JCMT or for CSO. The allocation of a block of time for SBI does depend on scientifically competitive proposals being approved by the time allocation groups for the two telescopes.

RxW

The commissioning dates for RxW are not yet known and, unfortunately, as for previous semesters, the commissioning dates will be after the regular PATT deadline. It will not be possible to accept applications which specifically require the features and sensitivities of the RxW instrument. Therefore the D-band (690 GHz) section is not available for semester 97A. C-band observations can be applied for assuming that the project can be completed using the existing RxC2. If, and when, RxW is commissioned, all outstanding C-band applications will be transferred to use the new instrument.

SCUBA

SCUBA will be undergoing further commissioning during semester 97A. In addition to this work there will also be ample opportunity for observations.

The SCUBA 2nd round begins in early December and continues through the end of semester 96B, which has been extended to include February 1997.

Telescope Time Allocations

PATT ITAC Report for Semester 96B

Allocations

The individual partner TAGs hold meetings in their respective countries prior to the PATT session to assess applications from their own country. At these meetings informal numbers of shifts are nominated for each application in a priority order. The Chairpersons of each TAG bring their respective lists to the PATT where the ITAC combine the awards, include discussion of the engineering and commissioning requirements and assess the international applications. The final allocations of shifts are made by the ITAC.

Applications to be considered	
UK status	39
Canadian status	32
Netherlands status	9
International status	10
University of Hawaii	5
TOTAL:	95

The PATT meeting was held at The Falcon Hotel in Stratford upon Avon, UK on 4th & 5th June 1996.

Time Available (in 16-hour nights)	
No. of nights in semester 96B	183.0
Engineering & Commissioning	64.0
Set aside for SCUBA 2nd round	50.0
University of Hawaii (10%)	7.0
Director's discretionary use	4.0
Available for PATT science:	58.0

The above table indicates the order in which nights are removed from the total available for the semester. Semester 96B covers a winter period from 1st August 1996 through 31st January 1997 inclusive. A further 28 nights of SCUBA 2nd round have been added by including February 1997 into semester 96B.

Awards (in 16-hour nights)	
UK status	26.75
Canadian status	12.5
Netherlands status	10.0
International status	8.75
University of Hawaii	7.0
TOTAL allocation:	65.0

Designated Service time

Allocations for this semester are:

CDN	=	0 shifts allocated;
NL	=	0 shifts allocated;
UK	=	2 shifts allocated

Non-standard Instrumentation

The Lethbridge Group have again requested to bring their own Fourier Transform Spectrometer (FTS) system, which will be located on the right-hand Nasmyth platform (the other side from SCUBA).

Applications with Long-Term Status

L/M/96A/U14 completes its award with 2 shifts in 96B. L/M/96A/C08 was given a further 1 night shift and 3 day periods in 96B. L/M/Y/C05 and L/M/96A/C23 are Canadian student thesis projects. These continue to get time wherever possible until they have been completed.

Use of Daytime Periods

The ITAC can only allocate observations during the night periods from 17:30 through 09:30. They can recommend to the Director JCMT that certain applications should be considered for daytime observing. Any allocation of time thus given, at the Director's discretion, does not come from the national quotas.

Engineering & Commissioning

In view of the large amount of E&C time set aside for the commissioning of new instrumentation, other E&C tasks have been kept to a minimum for the semester.

Commissioning of the antenna and instrumentation continues with periods required to characterise and improve the surface via metrology and beam map measures, monitor the antenna performance and tracking through pointing and inclinometry runs, measure receiver performances and efficiencies, and increase the catalogue of standard spectra available at the telescope.

One week of 'heavy engineering' has been set aside for re-grouting and welding up to 8 further joints on the antenna azimuth track.

Time has been allocated for commissioning of RxB3, RxW and for SCUBA according to the commissioning plans made available by the instrument builders. There is a non-standard instrument configuration schedule for the new FTS system which requires set-up and calibration time on the right-hand Nasmyth platform.

A short-baseline interferometry session (SBI) has been arranged with the CSO to be run in November 1996.

SCUBA 2nd Round

A total of 156 shifts (the month of February 1997 has been included in this) have been set aside from the latter half of semester 96B to be allocated for continuum observations pending the successful commissioning of SCUBA. It is anticipated that the distribution of these shifts will be according to the partner percentages.

Once the sensitivities of SCUBA are determined, an announcement of opportunity will be widely circulated requesting applications for time to fill this slot. Applications should be sent to the national TAGs (2 copies) and to Hawaii (2 copies) where they will be peer-reviewed and assessed as normal prior to formal allocation by the ITAC. International applicants should send 4 copies to Hawaii.

These applications must be for single point photometry and 'jiggle' imaging only within the restrictions given in the announcement. Proposals for this round will be restricted to no more than 24 hours integration, including overheads. All observations will be done in serviced mode with no facilities for remote eavesdropping being provided at this stage.

Provisional dates will have the announcement circulated at about the end of July with a closing date for applications of 6th September (applications must bear a postmark no later than this date). The ITAC meeting will be held at ROE on 29th October.

Fallback Programmes

A number of applications have been approved by the ITAC to be included in the schedule should RxB3 and/or RxW fail to meet their delivery schedules. The commissioning time set aside for these instruments will be apportioned according to the partner funding ratio after 10% has been given to the University of Hawaii. Applicants on these fallback programmes will be informed by the JCMT Scheduler when/if their time is to be scheduled.

In addition, there are numerous heterodyne applications set aside to be included as fallback for the SCUBA 2nd round. It is most likely that all these fallbacks will be done in serviced mode by JCMT staff. All applicants awarded fallback will be informed in advance by the JCMT Scheduler.

Modification of the Semester Boundary

In order to accommodate a significant period of time for the SCUBA 2nd round, the ITAC have decided to include the month of February 1997 effectively into semester 96B. Therefore the month of February will be scheduled as part of the SCUBA 2nd round.

Semester 97A will be a 5-month semester, beginning on 1st March 1997 and ending on 31st July 1997. The closing date for applications for this semester is 30th November 1996 (for **ALL** applications). The national TAGS will meet in early January with an ITAC meeting towards the end of the month.

The Allocations Table

Listings in the following table reflect the allocations made by the ITAC. Subsequent re-scheduling may already have modified some of these awards and added others.

Graeme Watt, JAC
(ITAC Technical Secretary & JCMT Scheduler)

Successful JCMT Applications for Semester 96B

PATT No.	Principal Investigator	Shifts Given	Title of Investigation
C01	Naylor D A	4	Search for tropospheric CO absorption in Neptune
C03	Wilson C D	3	The disk properties of high luminosity class 0 protostars
C05	Hasegawa T I	2	Observations of non-dissociative shocks in molecular clouds
C11	Clark T A	1	Limb distribution and mapping of the n=19-20 emission on the Sun
C12	Davis G R	1	Brightness temperature spectrum of Jupiter
C15	McCutcheon W H	3	Excitation conditions in NGC 6334
C16	Matthews H E	0	(+2 day periods) Interstellar & cometary ices: ... in Hale-Bopp
C19	Hasegawa T I	1	Photochemistry in small clouds
C24	Wilson C D	3	Warm gas & dust in the cores of ultraluminous infrared galaxies
C27	Jackson J M	4	Low metallicity photodissociation regions: IC 10
Y/C05	Papadopoulous P	2	Temperature, density gradients of the molecular gas in Seyferts
96A/C08	Matthews H E	1	(+3 day periods) The evolution of the coma of comet Hale-Bopp
96A/C23	Giannakopoulou J	0	(3 shifts during SCUBA 2nd round) Clues to the formation of giant H II regions: The molecular gas content ... in M101
H01	Carpenter J	8	An unbiased survey for massive dense cores
H04	Owen T	2	(+2 day periods) Neptune, Titan & Hale-Bopp
H05	Jewitt D	4	(+4 day periods) Monitoring of CO emission from Hale-Bopp
I02	Clancy R T	1	(2 x 1/2 shifts) Mars & Earth atmospheric studies
I06	Zuckerman B	1	(2 x 1/2 shifts) Molecules in protoplanetary disks
I08	Moriarty-Schieven G	2	Evolution of accretion disks of embedded young stellar objects
I10	Jewell P R	1.5	The size & excitation of the Alpha Ori CO envelope
N01	Israel F P	3	[C I] and CO in galaxy centres
N02	Israel F P	4	CO excitation of dwarf galaxies
N03	van Dishoeck E F	4	Physical and chemical evolution of star-forming regions
N04	Hogerheijde M	1	Probing the envelopes of YSO's in Taurus & Serpens:
N05	Israel F P	4	Radial distribution of molecular gas in M 33
N07	van der Werf P	2	Confirmation of high-z [C II] 158 micron absorption
N08	Israel F P	1	Excitation of cold CO in big bulge galaxies
N09	Wesselius P R	1	[C I] in the ISM
U04	Ward-Thompson D	3	The growth of protostellar accretion disks
U05	Williams D A	6	Direct test of chemical desorption from dust in molecular clouds
U06	Ward-Thompson D	5	Pre-stellar cores and the initial conditions for star-formation
U07	Greaves J S	3	Are dust grains aligned by ion-neutral drift?
U10	Hatchell J	5	Temperature structure of protostellar outflows
U12	Dent W R F	3	A search for HCN in pre-planetary systems
U15	Hoare M G	1	Dust tori in relation to the ionised winds in luminousYSO's
U18	Guilloteau S	4	Spectroscopy of T Tauri disks: the physical properties of disks
U19	Chandler C J	8	Temperature effects in the classification of low-mass protostars
U20	Richer J S	4.5	Excitation & energetics of molecular clouds: Testing models of outflow acceleration
U22	Davies J K	3	(+3 day periods) Chemical monitoring of comet Hale-Bopp
U33	Gibb A G	4	Probing the small-scale structure & evolution of the HH24-26 molecular cloud core
96A/U14	Gray M D	2	SiO J = 7-6 masers in R Aqr: Testing the 'clump' model for maser emission

Weather and Fault Statistics

The following tables present the weather loss and fault loss for semester 96A. Full details are stored on database at the JAC and interested readers are referred there for further information. ***The total clear time lost from primary programmes for this semester is 6.1%***

Semester 96A

Month (1996)	Hours available	extended hours used	primary programme lost to weather (hours)	%	backup programme lost to weather (hours)	%
February	440.1	18.9	177.8	40.4	139.3	31.6
March	500.5	36.2	150.9	30.1	150.9	30.1
April	432.0	17.3	24.5	5.7	8.5	2.0
May	472.0	38.8	50.9	10.8	28.9	6.1
June	454.5	8.3	76.1	16.7	76.1	16.7
July	464.0	16.2	53.2	11.5	52.2	11.3
Total	2763.1	135.7	533.4	19.3	455.9	16.5

Table 1: *JCMT weather statistics.*

Semester 96A

Month (1996)	Hours available	Total	ANT	INS	COMP	SOFT	CAR	OTH
February	440.1	7.4	2.0	2.9	1.9	0.1	0.5	0.0
March	500.5	50.9	0.0	36.9	0.4	0.0	5.5	8.0
April	432.0	17.1	0.3	12.8	2.7	1.2	0.0	0.1
May	472.0	32.4	6.1	17.0	1.4	1.7	5.8	0.4
June	454.5	20.1	0.6	8.2	1.0	1.4	0.0	9.0
July	464.0	7.1	5.0	1.3	0.0	0.2	0.0	0.6
P(hrs)	2763.1	135.0	14.0	79.1	7.4	4.6	11.8	18.1
B(hrs)		8.8	0.0	8.1	0.5	0.2	0.0	0.0

Table 2: *JCMT fault statistics. Wherever possible the faults are categorised into ANT = antenna; INS = instrument; COMP = computer hardware; SOFT = software; CAR = carousel; with the remainder going to OTH = other. The figures in the table may not appear to add up correctly due to rounding in the original program.) P defines the time lost from Primary projects. The category B(hrs) is the time lost to Backup projects.*

TECHNICAL NEWS

SCUBA comes to JCMT!

No doubt many readers will have been waiting for SCUBA first light almost as avidly as the SCUBA project team and those that have been keen enough to follow the updates on the SCUBA web page will already know how things have been going, but the Newsletter is an appropriate place for a more detailed summary of exactly where we are and what still remains to be done.

The good news...

SCUBA was delivered to the JAC from ROE in early April and, after a very successful assembly and cooldown in Hilo, during which time local staff were trained in assembly and operation of all aspects of the instrument, it was transported to JCMT where it was re-assembled and mounted onto the telescope. There were no major problems, a tribute to the careful planning and hard work of the team and the local staff. Base temperature of 75 mK was reached on 14th June. Tests at this time revealed that there were only 2 dead pixels out of 131, and 2 more that had very high noise, leaving 127 operational pixels out of 131, or 97%.

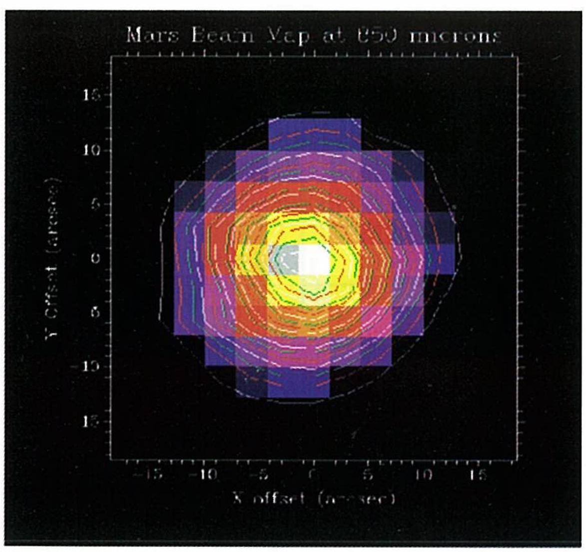

Figure 1: SCUBA beam map of Mars

There was a three-week period of daytime testing before first light was obtained on July 8th. The images obtained that night were not terribly exciting, just Uranus and Jupiter, and were somewhat distorted due to a timing mismatch between SCUBA and the chopping secondary mirror. However, such teething problems were rapidly sorted out and in Figure 1 we present what was the first 'proper' image of Mars taken a little while later. Mars is effectively a point source in the SCUBA beam so that its image represents a beam map of the centre pixel on the LONG-wave array.

Things up to this point had gone so well that some of us had a feeling that something had to go wrong soon, and sure enough it did! A wiring failure inside the cryostat led to the loss of signals from the SHORT-wave array the very day after first light! Fortunately, we did obtain enough information on the first night to allow us to estimate that the sensitivity of the SHORT array at 450 microns was close to that predicted.

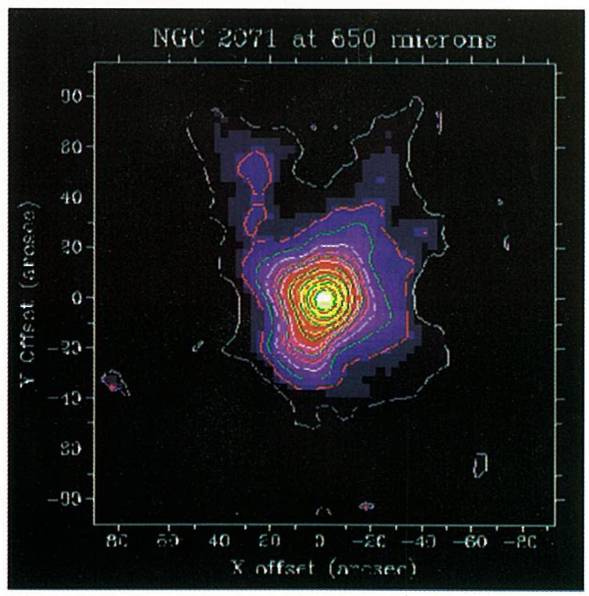

Figure 2: SCUBA image of the star-forming region NGC 2071.

Over a month since first light very successful progress has been made in commissioning the different observing modes of SCUBA and ironing out the inevitable problems and bugs in such a complicated system (and one so radically different from what has been used before). We are now able to offer service observing during the latter part of the extended semester 96B. There will be a break in the commissioning programme for September when

SCUBA will be warmed up and opened to fix the wiring fault that caused the loss of the SHORT-wave array and a few other problems.

Pointing, focussing, skydipping, point-source photometry and jiggle-mapping of sources of size less than the field-of-view of the instrument have all been successfully commissioned. At the time of writing, we are starting the procedure of flat-fielding the LONG-wave array. In Figure 2 we show a map of the galactic star formation region NGC 2071 which took just over 5 minutes of integration on a wet night and on the back cover of the Newsletter we show an image of W 48, another galactic star-forming region. Readers should note that these images are not properly flat-fielded or calibrated, and are basically just semi-raw data.

The not-so-good news...

As mentioned above, no measurements could be made with the SHORT array after the first night. This is due to a wiring failure which will be fixed when the instrument is warmed up at the end of August. Some channels also seem to be sensitive to vibration from the chopping secondary mirror. We think we have identified the area of the wiring that is sensitive and intend to fix this as well when SCUBA is open in September.

The sensitivity of the LONG-wave array is not as good at present as originally hoped. This is due to an excess of background radiation which we believe to be caused by a leak in a blocking filter, a new one of which is being built at QMW and which should also be replaced during the warmup in September. A similar problem had previously been found with the 3 photometric pixels and fixed.

What's next?

As described above, there is a warmup scheduled for the end of August at which time it is hoped to fix the dead channels, reduce the sensitivity to vibration, and reduce the background on the LONG-wave array. After reassembly and cooldown, commissioning will begin again in early October, when we will begin flat-fielding the SHORT array and also begin work on the more complex observing modes, such as scanning the array over large areas.

Service observations will be performed during the extended semester 96B in December, January and February. The call for proposals has already been sent out and the relevant technical details of SCUBA are reprinted below.

Walter K Gear, JAC, SCUBA Project Scientist

SCUBA Technical Details

Summary of the Instrument

SCUBA is both a camera and a photometer covering all the atmospheric windows from 2.0 mm (150 GHz) to 0.35 mm (900 GHz). It has two arrays of detectors which look at the same area of sky simultaneously: one hexagonal array of 91 pixels optimised for 450 microns (the SHORT array) and one hexagonal array of 37 pixels optimised for 850 microns (the LONG array). The SHORT array can also be used at 350 microns and the LONG array can also be used at 750 and 600 microns. Both arrays are diffraction limited with a field-of-view of approximately 2.3 arcminutes, however both arrays undersample the focal plane, which has implications for observing, as described below. In addition to being able to use the two arrays to make images or do point-source photometry in two of the submm windows simultaneously, SCUBA also has the capability to make single-pixel measurements with three additional pixels at 1.1, 1.3 and 2.0 mm. These 3 additional pixels look out at the sky at the same time, but NOT at the same position.

Sky Emission

As with all submm instruments emission from the atmosphere above the telescope is a major problem for SCUBA. The high background power is effectively a large DC offset to the astronomical signal and intrinsic fluctuations in the background cause photon noise. Systematic variations in the background can also add yet more noise and affect bolometer sensitivity, as well as being associated with changes in atmospheric transmission and with scintillation. SCUBA adopts the conventional approach to minimising the effect of sky background variations by chopping the source against a reference sky position to remove the DC offset and cut down the noise due to high-frequency sky variations, and by nodding the telescope to cancel slower varying quantities such as beam imbalance and telescope spillover. During normal operation the secondary mirror will be chopped at 7 Hz and the telescope will be nodded every 10-20 sec. It is also intended to use three-position chopping and nodding to gain even better sky cancellation, however this has not been commissioned yet and will not be available for the service observations.

Sensitivity variation

Variations in sky background (for instance as one goes from zenith to low elevations) change the power falling onto the bolometers and affect their sensitivity. These variations are detected and removed by measuring the signal from a constant calibrator source inside the cryostat. The calibrator signal is modulated as a sine wave at 2 Hz.

Image sampling

The arrangement of bolometers in the arrays is such that SCUBA undersamples the image plane by a factor of about 4. When the source is smaller than the array a fully-sampled image is obtained by taking a series of short 1 second exposures offset from one another in a hexagonal pattern designed to fill-in the gaps between the bolometers. The offsetting is achieved by "jiggling" the secondary mirror of the telescope. If only the short-wave array is being used then full sampling can be achieved using a 16 point pattern with individual points spaced roughly 3 arcsec apart. Similarly, the long-wave array can be sampled with a 16 point pattern with 6 arcsec spacing. Using both arrays together, however, requires a 64 point pattern with 3 arcsec spacing to cover the area between the long-wave bolometers at the resolution required by the short-wave array.

Nodding the telescope every 10-20 seconds to remove the effect of background variation is not a problem if a 16 point jiggle pattern is being used as such a pattern only takes 16 seconds to measure. However, measuring all the positions in a 64 point jiggle pattern before nodding the telescope would give a time between nods that is longer than desirable. The solution is to split the jiggle pattern into 4 sections of 16, each to be measured in all nod positions before the next is begun.

For mapping large sources with SCUBA a scanning method will be used, however this is not yet commissioned and will not be available for these service observations.

The first observing round

At this point in time applicants should be concerned solely with the scientific programme they want to pursue, subject to the constraints imposed by the limited observational modes and the sensitivities that can be guaranteed at this time. Successful applicants will receive more detailed information on how to plan their actual observing programme, but for now the primary guidelines are as follows:

1) Only applications for observations of sources smaller than 2.3 arcminutes will be considered. Do not attempt to get round this by asking for a list of sources 2.3 arcminutes apart!

2) Only programmes requiring up to a total of 24 hours of telescope time, including the overheads as described below will be considered.

3) Only programmes requiring integrations on individual sources of less than 2 hours will be considered.

4) Photometry with the arrays can be performed in the following pairs of filters simultaneously: 350:750, 450:600, 450:850, 350:850. Photometry can also be performed separately using the three longer wavelengths (1100,1300 2000).

5) The shorter the wavelength, the less efficient the dish is and the more subject to weather the sensitivity is. Applicants should think about whether they really need photometry at those wavelengths, and if so, how faint they want to go. If you ask for photometry with the LONG array, then the SHORT data comes free, however the sensitivity may not be what you require. Under reasonable weather conditions however, for a thermal source with a spectrum rising as frequency cubed you should get comparable S/N at 850 and 450 simultaneously. You are likely to do worse at 350 than at 450, even for a frequency cubed or to the fourth power spectrum under good conditions.

6) Maps can be made in the same combinations of filters as for photometry, again the question of whether you really want to struggle hard for data at the shortest wavelength applies. There is an added complication here however due to the requirement to obtain fully-sampled images, as described above. If you ONLY need 850, or you ONLY need 450 then a 16-position jiggle is required. However if you want to get both at the same time you need to do a 64-position jiggle. This does not affect performance or efficiency over a long integration however, as when oversampling you are effectively just increasing the integration time. There is likely to be no gain in spatial resolution at 350 compared to 450.

7) Small maps, of the order an arminute, can also be made with the photometric pixels.

8) In planning integration times required, applicants should use the following table of sensitivities and assume noise integrates down as the square root of time. [These sensitivities already take chopping into account].

HOWEVER applicants must also add on an overhead to account for overheads during integration (mainly for nodding) plus slewing time, pointing, and calibrations. These all add up to a total of approximately 50 %.

Beamsizes & Sensitivities

(a) Array Filter Combinations

SHORT:LONG				
FWHM (arcsec)	NEFD (mJy)	SHORT:LONG	NEFD (mJy)	FWHM (arcsec)
7*	1400*	350:750	200	11
7*	1000	450:850	80	13
7*	1000	450:600	500*	10
7*	1400*	350:850	80	13

* = estimated, not yet properly determined

(b) Photometric pixels

Wavelength	FWHM(arcsec)	NEFD (mJy)
1100	16	60
1300	18	60
2000	28	60

Release of Spectral-Line Five-Points

All users of JCMT are (or should be) quite familiar with checking the pointing regularly using a nearby continuum source to provide small pointing corrections to the telescope. We do have good pointing, better than 2 arcsec rms, but even so, it is often necessary to apply small pointing corrections, especially after long slews or if the weather conditions are changing.

At JCMT pointing is done by using a five-point routine, although some radio telescopes prefer to do it by cross-scans. The five-point scan measures the signal strength at the nominal tracking position, as well as at four points spaced half a beam-width away north, south, east, and west of the center. These data are then fed into a least squares fitting program with the constraint that the beam-size is known, or in case of extended sources, that the convolved beam-size is known. This method works surprisingly well, even in cases where the source is off by more than half a beam-width. The pointing can be checked this way with all of our common user receivers, because they all have a continuum mode.

At high frequencies (even B-band), the number of continuum sources are rather limited for our line receivers. The continuum sensitivity is low, and the bulk of the pointing sources, *e.g.* blazars, are faint. We have therefore decided to also provide a pointing mode, which allows pointing in spectral line configuration, *i.e.* to use AGB-stars for pointing. Pointing on point-like spectral line sources is by no means a new concept, most radio telescopes have used this technique for years, especially on strong maser sources (H_2O and SiO masers). Although some efforts were used several years ago to provide JCMT with the ability to do spectral-line five-points, it was not until last year that the software was finally implemented and debugged by J. Scobbie. At the same time we also released a new version of the JCMT pointing catalogue.

The spectral-line five-point mode was officially released in January 1996. It has not been used very much, presumably because observers are not aware that it exists, but it is very simple. It looks identical to a normal five-point. The only difference is that instead of choosing the continuum backend, you will have to use the DAS with 125 MHz bandwidth and non-continuous calibration. The last section of the pointing catalogue has all the necessary information on stars suitable for spectral line pointing, and what the program needs is the radial velocity and the linewidth over which to integrate. It is therefore necessary to be in velocity mode, or if not, to set the correct velocity, because the integration range is determined relative to the center. The software then takes the integrated line intensities, as well as errors, and uses the same least squares fitting routine that is used for continuum pointing.

The only drawback with spectra-line five-points is that one has to be tuned to one of the main CO transitions, J=2-1, 3-2, or 4-3. In some cases it is possible to use CO isotopomers or molecules like CS and HCN, but these sources are currently not flagged in the catalogue. Unless you, or your support scientist, is very familiar with the chemistry of AGB-stars, don't try it. It should also be mentioned that some AGB-stars have somewhat uncertain coordinates, and we tried to identify and correct the positions of all the stars that we found, but there may still be a few discrepancies in the catalogue.

Please try it out, especially if you have a RxC2 program, because in the C-band there are hardly any pointing sources except planets and a few strong compact H II regions and 'protostellar' sources. Further information about spectral line fivepoints can be found on the JCMT web pages.

Göran Sandell, JCMT

The Demise of the JAC & JCMT Vax Systems

With effect from August 5th, the JAC and the JCMT computer access for staff and visitors will be entirely through the Unix-based workstations. There will be no user access to VMS-based computing facilities.

Although the current JCMT operating system runs on VMS, the Vax machines will not be generally available to users. Files created on the Unix machines which are necessary to carry out observations, such as user-created source catalogs and pattern files, will be able to be read by the telescope control Vax.

Serviced & Flexible Programming

During semester 96B (and continuing into semester 97A and beyond) there is a considerable amount of time set aside for the commissioning of high-frequency instruments (SCUBA & RxW). Both these commissioning tasks will require excellent weather conditions in order to fully understand and quantify the observing parameters and sensitivities. Therefore a large number of 'fallback' applications have been nominated by the ITAC for use either when the weather is not suitable for commissioning or when the instrument is in need of repair. These applications will be completed in serviced mode by members of the JCMT support team.

In addition to the above, it is intended that as many C-band applications as possiible are designated for flexible scheduling against lower frequency applications. In this case it is likely that the C-band observers may be present for their observations but, if the weather is not sufficiently good for their project, these observers may be requested to proceed with a lower frequency application in serviced mode. In such a situation a member of the JCMT support team will coordinate all the serviced observations. In many cases the C-band observations will be completed in serviced mode also to allow maximum flexibility.

Therefore it is in the applicants best interest to supply the fully completed serviced application forms promptly to the JCMT staff (either to the designated staff support member or directly to Graeme Watt) so that sufficient details are available on the summit to proceed with whatever application is most appropriate to the weather conditions at that time.

visit the JCMT homepage on the World-Wide Web at:

http://www.jach.hawaii.edu/JCMT/home.html

for all the latest progress information, observing details, and up-to-date images and photographs of SCUBA try:

http://www.jach.hawaii.edu/~wsh/scuba/scuba_home.html

SCIENCE HIGHLIGHTS

Physical Conditions in Molecular Clouds in M33

We have used the JCMT to observe the ^{12}CO J=2-1, ^{13}CO J=2-1, and ^{12}CO J=3-2 lines in a sample of seven giant molecular clouds in the Local Group spiral galaxy M33. The clouds were chosen to cover a wide variety of star formation conditions, from clouds with no optical H II regions to a cloud located in the brightest giant HII region in the galaxy. Determining the physical conditions inside molecular clouds is important for understanding the link between the properties of the molecular gas and the types and amount of stars that are formed. Cloud properties that could affect the star formation process include the temperature and density of the molecular gas, as well as the mass fraction in high density gas. In return, star formation, particularly massive star formation, can affect conditions inside molecular clouds by compressing the gas at the boundaries of stellar wind or supernova shocks and heating the gas by increasing the ultraviolet radiation field.

The ^{12}CO/^{13}CO J=2-1 line ratios are very uniform, with an average value of 7.3 and an *rms* dispersion of 1.3 (18%). This average line ratio compares quite well with values measured in other spiral galaxies, and is slightly smaller than the value measured in the starburst galaxies (13 ± 5, Aalto *et al.* 1995). The ^{12}CO J=3-2/J=2-1 line ratios show more scatter. In particular, the line ratio obtained for NGC 604-2 (1.07) is significantly higher than the value for any other cloud. Excluding NGC 604-2, the average ^{12}CO J=3-2/J=2-1 line ratio is 0.69 with an *rms* dispersion of 0.15 (21%). Thus we conclude that the ^{12}CO J=3-2/J=2-1 line ratio is uniform across six of the seven clouds in our sample, but is significantly enhanced in NGC 604-2. This average line ratio for the six clouds in M33 is in good agreement with values measured in other starburst and normal galaxies, while higher line ratios similar to the value for the cloud NGC 604-2 are seen in the nuclei of both NGC 253 (Wall *et al.* 1991) and M51 (Garcia-Burillo *et al.* 1993).

If we compare the CO line ratios for the three clouds without H II regions (MC19, MC32, and NGC 604-4) with those for the clouds with normal H II regions (MC 1, MC 13, and MC 20), the average line ratios for the two sets of clouds agree very well. The one cloud with a large ^{12}CO J=3-2/J=2-1 line ratio, NGC 604-2, is located in the very intense star formation environment of the giant H II region NGC 604. The difference between the two clouds (NGC 604-2 and NGC 604-4) in and around this giant H II region is striking. The projected separation of the two clouds is only 120 pc (30"), and yet their ^{12}CO J=3-2/J=2-1 line ratios are very different. Only the cloud in the immediate vicinity of the giant H II region and its powering OB association has an unusual line ratio.

The high ^{12}CO J=3-2/J=2-1 line ratio in NGC 604-2 may be a clue to unusual physical conditions in the molecular clouds from which the H II region NGC 604 formed, *i.e.* a pre-star formation difference in the physical conditions that may have caused the formation of the giant H II region. Alternatively, the high line ratio may be due to heating of the gas by the massive stars, *i.e.* a post-star formation change in the physical conditions in the molecular cloud. This interpretation implies that the giant H II region has a relatively small sphere of influence over which its intense radiation field can change the properties of the dense molecular gas. It appears that both an unusually intense radiation field and a cloud in close proximity to the source of the ionizing radiation are required to produce a significant change in the CO line ratios.

We used a large velocity gradient code to estimate the physical conditions in the molecular clouds in M33. To provide better constraints for the models, we include the ^{12}CO/13CO J=1-0 line ratio observed for these clouds in a 55" beam (Wilson & Walker 1994). We performed separate fits for the average line ratios for the six clouds and for NGC 604-2. The results from the LVG analysis show that there is a significant difference in the kinetic temperature of NGC 604-2 ($T_K \lesssim 100$ K) compared to the other clouds ($T_K \lesssim 30$ K). Thus the large ^{12}CO J=3-2/J=2-1 line ratio in NGC 604-2 is likely the result of the higher kinetic temperature of this cloud. In addition, the average solution suggests that NGC 604-2 has a higher column density by about an order of magnitude compared to the six other clouds. The molecular gas in the six clouds is quite dense (10^3 — 3×10^4 cm^{-3}). The volume-averaged densities for the six normal clouds are 40 — 290 cm^{-3}, significantly lower than the densities derived from the LVG analysis. Thus the volume filling factor of the dense gas within the clouds is <10%. For NGC 604-2 the volume-averaged density is somewhat higher, 500 cm^{-3}, which combined with the somewhat lower density from the

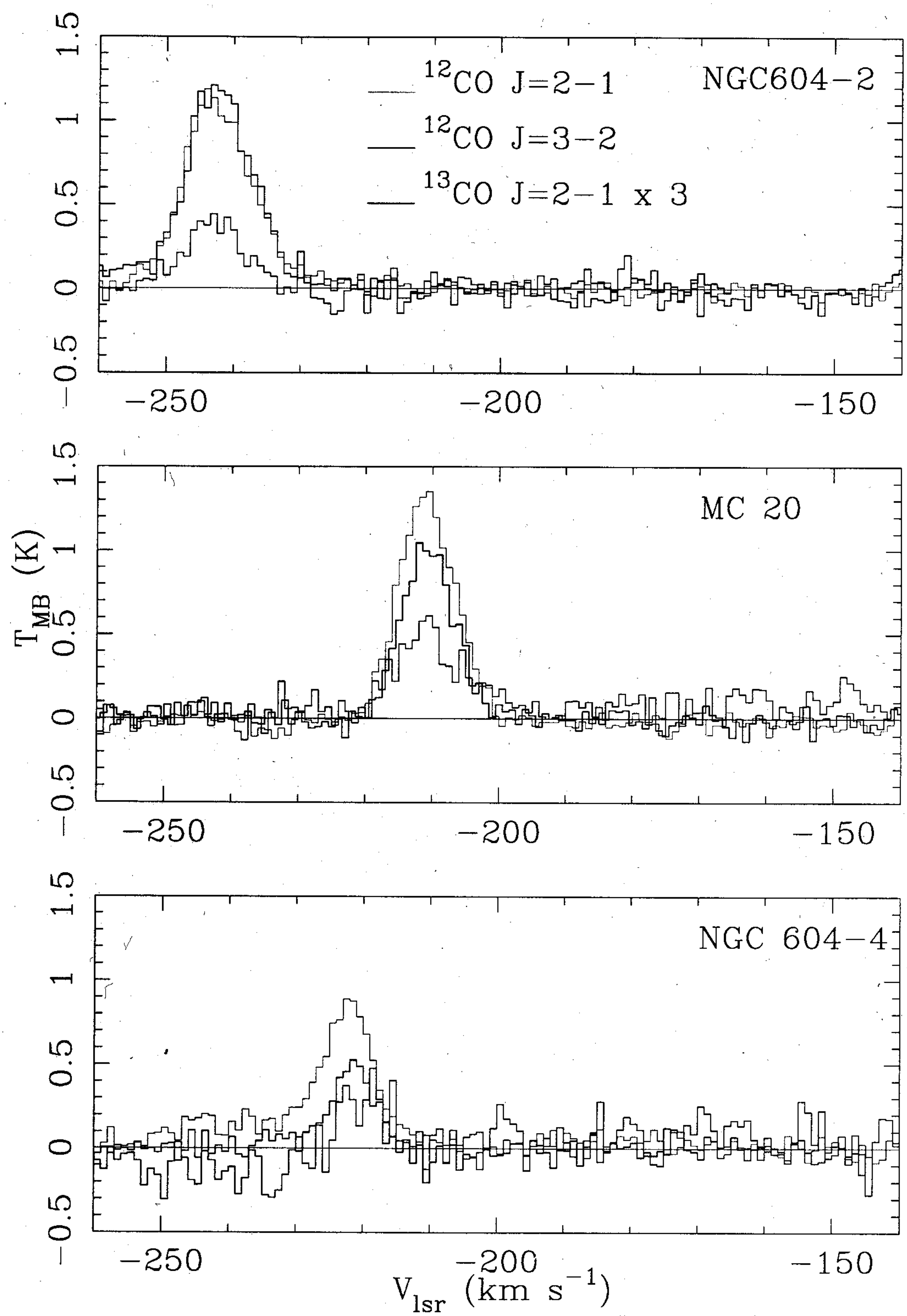

Figure 1: ^{12}CO J=2-1, ^{13}CO J=2-1, and ^{12}CO J=3-2 spectra for three of the seven giant molecular clouds in M33. The spectra are binned to 1 km/s resolution and scaled to the main beam temperature scale. The ^{13}CO J=2-1 spectrum has been scaled up by a factor of 3. Note in particular the varying strength of the ^{12}CO J=3-2 line relative to the J=2-1 line.

LVG model of 1 — 3×10^3 cm^{-3} gives a filling factor for the dense gas of 17 — 50%.

Thus NGC 604-2 is distinguished from the other clouds by a larger column density, volume filling factor of dense gas, and kinetic temperature. The kinetic temperature of the gas is probably the physical parameter most easily affected by the presence of the intense burst of star formation in the giant H II region. The gas column density could be increased through shock-initiated merging of two or more molecular clouds or through a partial collapse of the molecular cloud due to an increase in the external gas pressure. However, the molecular column density could also be decreased through photo-dissociation of the molecular gas and thus it is difficult to predict the net effect on the column density from the formation of the giant H II region. It is tempting to speculate that the higher column density and filling factor of the dense gas in NGC 604-2 (or clouds like it that have since been destroyed) could have played a role in initiating the burst of star formation that formed the giant H II region.

The uniformity of the line ratios of the six molecular clouds observed in the normal disk of M33 suggests that similar observations of ensembles of molecular clouds in more distant galaxies are likely to produce meaningful measurements of the average physical conditions of the molecular gas. The relatively small sphere of influence (100 pc) of the giant H II region NGC 604 suggests that in normal galaxies only the most intense star forming regions may produce significant changes in the molecular gas. The change in the line ratios is likely to be measurable only in relatively nearby galaxies (< 10 Mpc), where the warm molecular gas in the H II region is not diluted by emission from cooler gas included in the beam. It would be interesting to test whether similarly uniform line ratios are observed in individual clouds in the intense ultraviolet field of a starburst galaxy, but such observations must await the construction of an imaging submillimeter interferometer, such as the Smithsonian Submillimeter Array.

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The Ionization Fraction in Dense Clouds

The ionization fraction of dense interstellar clouds is a crucial parameter of interstellar physics, since it influences the efficiency with which magnetic fields couple with the gas and ultimately controls the rate of collapse and star formation. Moreover, electrons and ions play a major role in interstellar chemistry. Stimulated by the sensitive receivers at submillimeter wavelengths and new laboratory measurements of the dissociative recombination rate coefficients, de Boisanger, Helmich and van Dishoeck (1996, A&A in press) have taken a new look at this problem. Using the JCMT, they have observed several different ions and their corresponding neutrals in two dense clouds, NGC 2264 and W3 IRS5. N_2H^+ is particularly strong toward NGC 2264: the figure shows a clear detection of the high-excitation 5 —> 4 line at 465.824 GHz. Both clouds have $n(H_2) \approx (1 - 2)\ 10^6$ cm^{-3} and $T_{kin} \approx 50 - 100$ K. Together, the abundances of the observed ions provide a lower limit to the ionization fraction of (2 - 3) 10^{-9} in both clouds.

In order to better constrain the electron abundance, a simple chemical model has been constructed, which uses observed abundances wherever available. The resulting electron fraction is $x_e = (1 - 3)\ 10^{-8}$ in the case of NGC 2264 and $x_e = (0.5 - 1.1)\ 10^{-8}$ for W3 IRS5. In the first case, the high abundance of N_2H^+ requires a high (cosmic ray) ionization rate of $>10^{-16}$ s^{-1}, even if all nitrogen is assumed to be in gas-phase N_2. For W3 IRS5, ionized metals such as Fe^+ and Mg^+ could provide ≈60% of the electrons.

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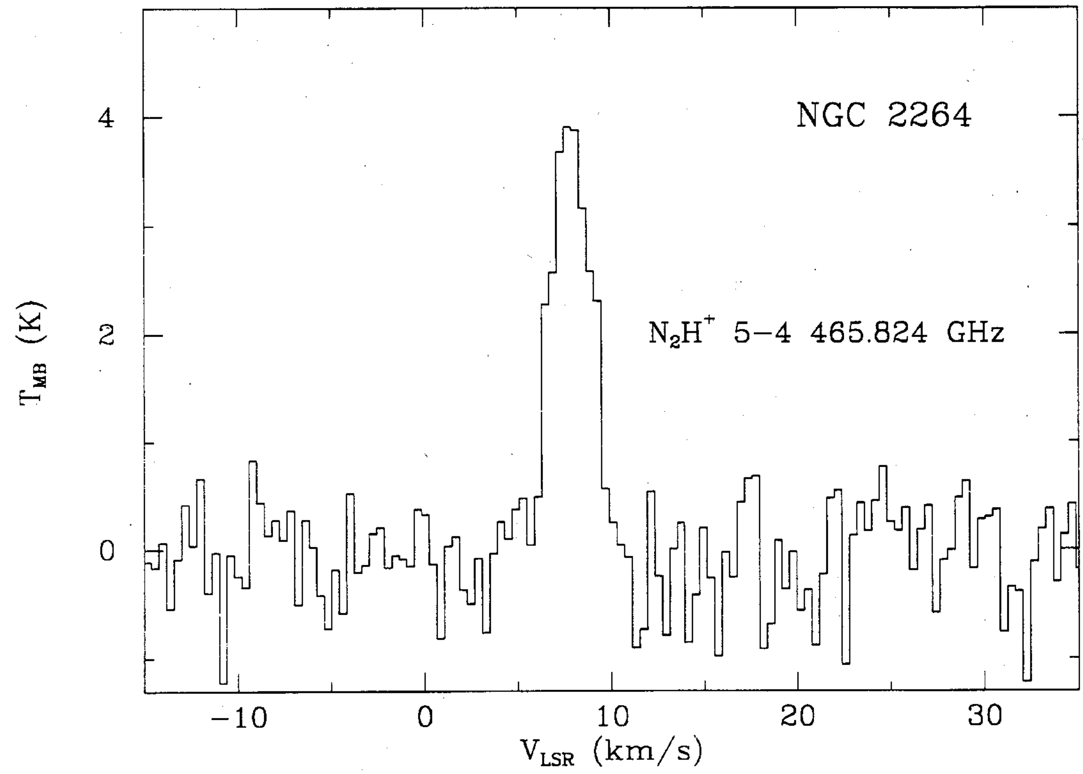

Figure 1: Observed N_2H^+ 5 - 4 spectrum toward NGC 2264 obtained with the JCMT and receiver C2.

Detection of the 464 GHz ground state line of HDO in W3(OH)/(H_2O)

H_2O is one of the most important interstellar molecules, but observations of it in interstellar clouds are greatly hampered by the Earth's atmosphere. However, deuterated water, HDO, possesses a number of (non--masing) low-excitation lines which can be observed from Earth. Although HDO was discovered already in 1975 through observations of the 1_{10} - 1_{11} transition at 80.6 GHz, most recent work has focussed on higher-lying transitions in the 230 GHz range. Because HDO is a light hydride, its ground-state 1_{01} - 0_{00} transition occurs in the submillimeter region, at 464 GHz. The line has been detected in Orion-KL by Schulz *et al.* (1991, A&A **246**, L55), but searches in other sources have so far proved elusive.

Helmich, van Dishoeck and Jansen (1996, A&A in press) used the JCMT to search for the 464 GHz line toward several young stellar objects in the W3 giant molecular cloud. The line is clearly detected toward the position of the water masers, W3(H_2O) (see Figure), and toward the compact H II region W3(OH), which lies only 7" to the west. These data form only the second detection of this line in the interstellar medium. The line was not seen toward W3 IRS5 and IRS4, but the conditions for these observations were not as good as those toward W3(H_2O).

Together with observations of higher-lying lines at 241 and 225 GHz, the 464 GHz data allow constraints on the HDO excitation. A detailed analysis shows that the higher levels are most likely populated by intense far-infrared radiation due to warm dust (T_{dust} > 100 K, E(B-V) > 500 mag). Combined with $H_2{}^{18}O$ data recently obtained by Gensheimer *et al.* (1996, A&A in press), the deuteration of water is found to be lower than that of other species, [HDO]/[H_2O] = (2 - 6) 10^{-4}, but comparable to that found for other "hot cores". One possible explanation is that the W3 cloud never went through a very cold phase in its history.

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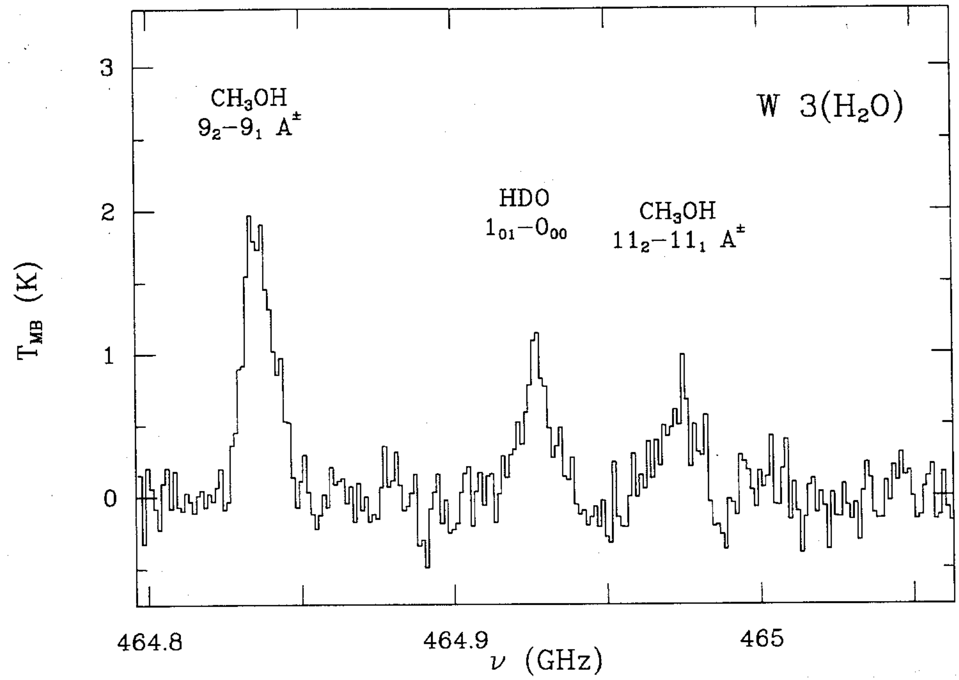

Figure 1: Double side band spectrum of the "hot core" W3(H_2O) obtained with receiver C2 and the DAS in the 250 MHz band width mode. Total integration time (on+off) is 90 minutes. The CH_3OH 11_2 - 11_1 $A^{\mp}$ line originates in the upper (image) sideband. Because of different calibrations of the two side-bands, its intensity should be multiplied by a factor of 1.4.

Magnetic Fields in the dust cloud M17-SW from Extreme-Infrared (800 μm) polarimetry

In the Extreme-Infrared (at submm & mm wavelengths), M17-SW is an elongated cloud with six roughly regularly spaced peaks of dust emission, as seen in the 800 μm continuum map (Fig. 3 in Padman & Prestage, 1992, JCMT-UKIRT Newsletter, **3**, 19) and in the $C^{18}O$ (1300 μm) spectral line map (Fig. 1 in Stutzki & Güsten, 1990, Ap.J., **356**, 513). Here we have obtained Extreme-Infrared (800 μm) linear polarization observations at the JCMT toward the elongated molecular cloud M17-SW. The six strongest dust peaks in total continuum intensity were observed. From our polarimetric observations, we find that the cloud's magnetic field is mostly perpendicular to the cloud's elongation.

Figure 1 shows the magnetic field results. The high angular resolution of the JCMT makes it more suitable for detecting the magnetic fields in the higher density gas (10^5 cm^{-3}) nearer the central ridge line of the cloud, *e.g.:* in denser cores. The proposed magnetic field lines across the M17-SW area are shown (long dashes). The six dust peaks P1 to P6 along a slightly curve ridge are shown within a light area (densest thermal gas density), and this ridge is surrounded by a darker area (medium gas density) and then by the cloud halo in the darkest area (lowest gas density). In the densest portion of M17-SW, the magnetic field directions are shown (thick bars with open circles at the six dust peaks P1 to P6). The lower angular resolution of the Kuiper Airborne Observatory (KAO) at 100 μm makes it more suitable for detecting the magnetic field in the lower density gas (10^3 cm^{-3}) in more extended but less dense halo-type areas (~2' or 1.3 pc). Polarimetry of M17 has recently been obtained with the KAO by Dotson (1994, PhD Thesis, Univ. Chicago). In the less dense portion of M17-SW in Figure 1, the halo magnetic field directions are shown as thick bars with filled circles (adapted from the KAO Far-IR data). JCMT measurements at peaks P4, P3, P2, and P1 show a changing magnetic field orientation over a short distance, consistent with the nearly zero polarization detected there at KAO with their larger beam.

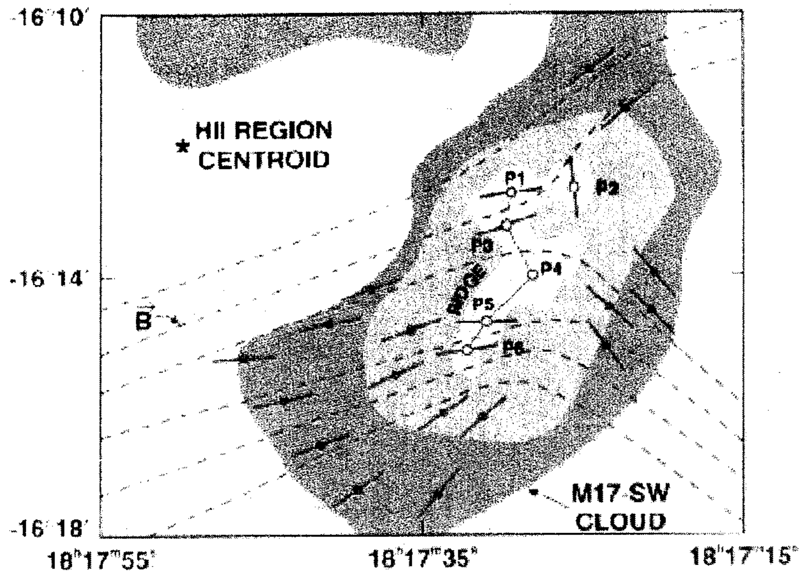

Figure 1: Magnetic field map of M17-SW — the proposed magnetic field lines across the M17-SW area are shown as long dashes (--). In the higher gas density areas, the thick bars show the magnetic field directions from our JCMT 800 μm data.

Theories. The role of magnetic fields in the evolution of molecular clouds and in regions of star formation is poorly understood. Many predicted strengths for the magnetic fields in molecular clouds have been published (*eg,* whether you assume magnetic equipartition or not). The magnetic field amplitude B cannot be deduced directly from the amplitude of the linear polarization, due to our incomplete knowledge of grains. We can use the total continuum emission I coming from dust particles to obtain the thermal gas density n, and the well-known statistical relation betweeen B and n, *i.e:*

$$B_{stat} = 0.4 \times 10^{-6} \text{ Gauss} . (n/cm^{-3})^{0.55}$$

to yield an estimate of B within a factor of 5. Many predicted shapes for the magnetic fields in molecular clouds have been published (see below). Many predicted scales for the magnetic field have been made, ranging from 10 kpc down to 0.1 pc. We grouped the theoretical models for the magnetic fields in molecular clouds into eleven 'magnetic classes', according to 2 parameters: the shape and the scale of the magnetic field involved.

Figure 2 shows our cartoon-style drawings with the main features for each magnetic class, as described further below. Class **A**: Cloud B-vectors are parallel to the galactic plane. Class **B**: B-vectors follow a U-shaped bowl, coming from the galactic halo and being parallel to the galactic plane at the bottom of the bowl. Class **C**: Cloud B-vectors follow the cloud elongation, except near the edges of the cloud where B-vectors enter and leave in a Y-shape fashion (taken at ±40° from the cloud elongation). Class **D**: Cloud B-vectors are perpendicular to the regional magnetic field (over 100 pc). Class **E**: Cloud B-vectors are parallel to the regional magnetic field (over 100 pc). Class **F**: B-vectors in clump centres parallel to cloud elongation, with pinching effects of magnetic field lines in clump edges (X-shaped). Class **G**: Cloud B-vectors are locally perpendicular to cloud elongation. Class **H**: B-vectors in clumps are perpendicular to cloud elongation, and B-vectors in-between clumps are aligned along cloud elongation. Class **I:** B-vectors in clumps are parallel to cloud elongation, and B-vectors in-between clumps are aligned perpendicular to cloud elongation. Class **J**: Cloud's B-vectors are skewed -20° from the direction of cloud elongation. Class **K**: B-vectors randomly oriented in clumps.

Comparisons. We defined two 'Acceptance Criteria', to compare model predictions to polarization observations, one on the differences between the observed B-vector PA (*ie* O_B) and the predicted B-vector PA (*ie* P_B), *ie* (O_B - P_B) should be $\lesssim$13°, and one on the standard deviation of the mean (*sdm*) should be $\lesssim$20°. **Results:** While four of the 11 magnetic classes of models satisfy the first criterion (means), and six of the 11 magnetic classes of models satisfy the second criterion (*sdm*), only two of the 11 magnetic classes of models can satisfy both criteria simultaneously (Classes E and G). The two

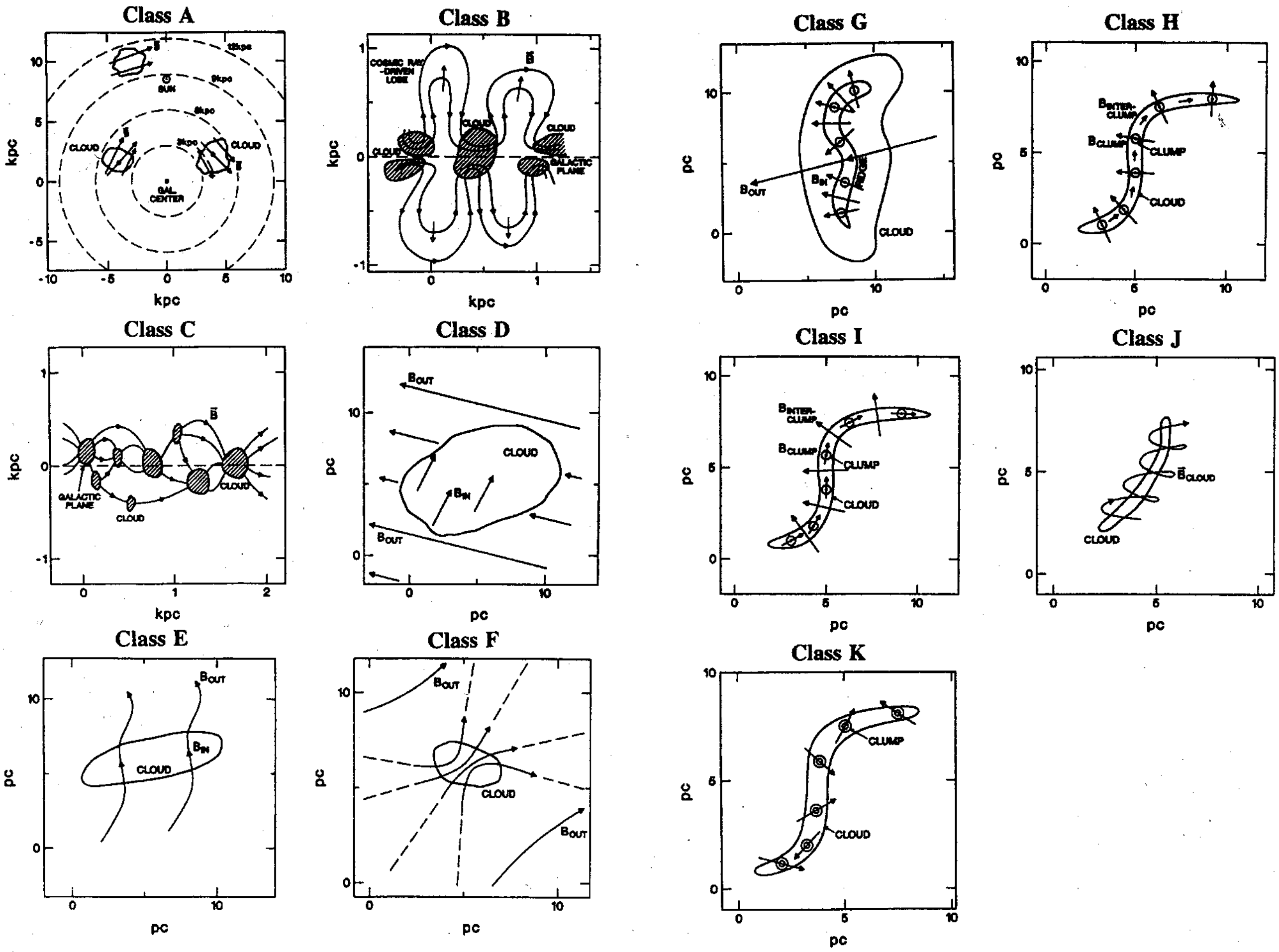

Figure 2: Cartoon-style drawings showing the main features of each 'magnetic class', described further in the text.

successful classes share in common the idea of an environmental magnetic field being perpendicular to the cloud elongation. This orientation has implications on star forming activities, favoring the formation of a large elongated disk (> 2000 AU) or cocoon, with a disk elongation perpendicular to the cloud magnetic field (and thus a disk elongation parallel to the cloud elongation).

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TW Hya from the Submillimeter to X-rays: Chemistry of a Nearby Protoplanetary Disk

The nearest well-studied regions of star formation lie 20-160 pc away, in the Taurus-Auriga, Ophiuchus, Lupus, and Chamaeleon dark clouds. Careful scrutiny of these regions has yielded the identification of many hundreds of embedded and associated T Tauri stars, which presumably formed out of dense molecular cloud gas. These T Tauri stars typically are about a solar mass or less and are only 10^5 - 10^7 yr old; as such they are our main source of information concerning the likely formative history of the Sun and planets.

In contrast, a handful of T Tauri stars are notable because of the absence of dark clouds in their general vicinity. TW Hya is the prototype of this group. It is fully 13 degrees from the nearest cloud (Rucinski and Krautter 1983). Yet there is little doubt as to its T Tauri status: like classical T Tauri stars, it exhibits strong Hα emission (as well as other optical emission lines), Li absorption, and excess continuum flux at near-infrared and ultraviolet wavelengths (Rucinski & Krautter). It is a strong submillimeter continuum source (Weintraub *et al.* 1989) and displays relatively strong CO emission (Zuckerman *et al.* 1995).

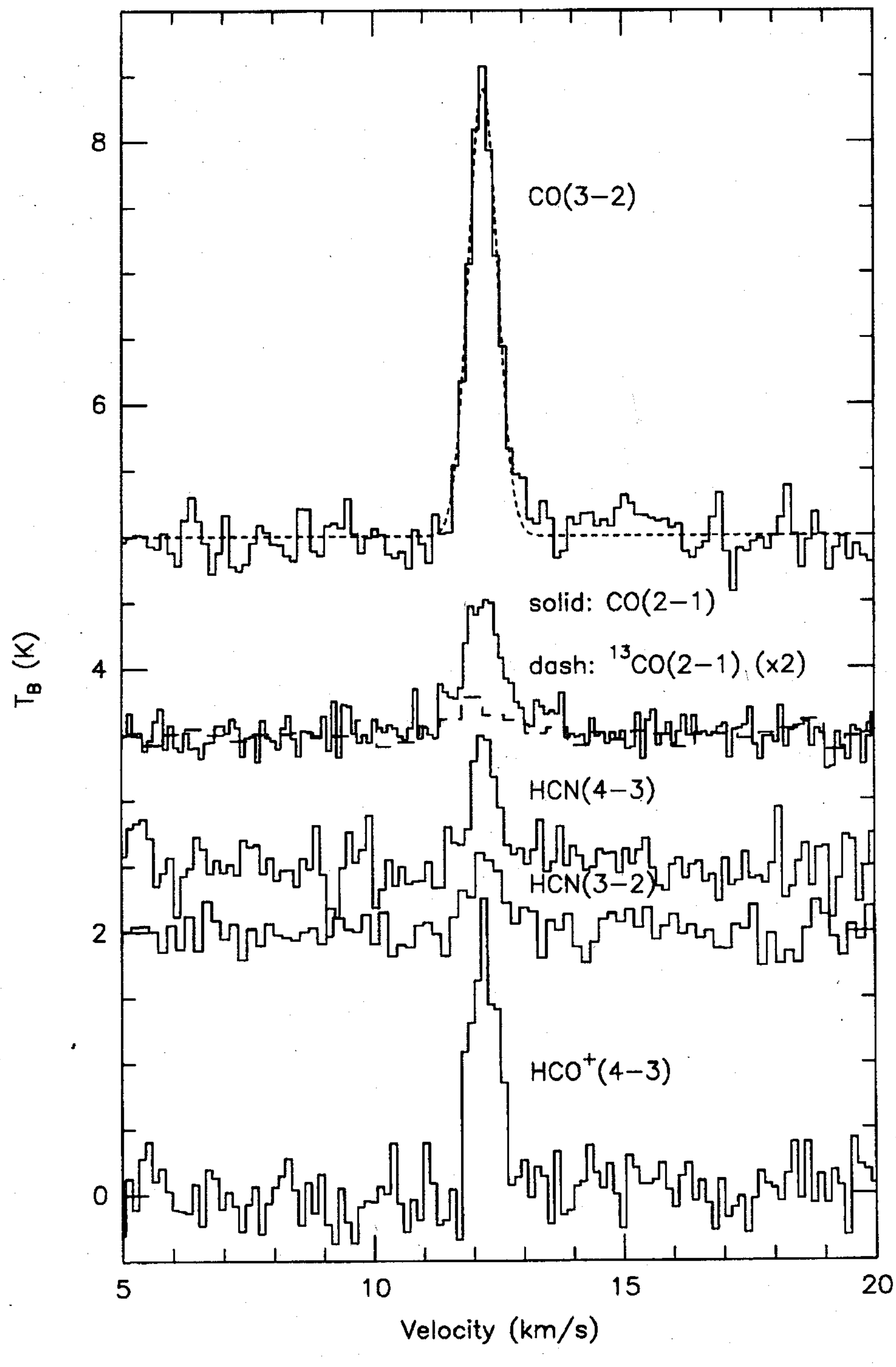

Figure 1: Molecular spectra observed toward TW Hya with the JCMT. Abscissa is heliocentric radial velocity and ordinate is relative main-beam brightness temperature. The dashed curve overlaying the CO (3-2) line profile represents the best-fit Gaussian.

Thus, it appears TW Hya possesses a compact, dusty molecular envelope that persists despite the general lack of interstellar molecular gas in its vicinity. Most likely the molecular gas orbits the star; specifically, given its narrow emission lines, the CO probably lies in a nearly face-on disk (Zuckerman *et al.*). Such a (relatively gas-rich) disk may closely resemble the early solar nebula. If TW Hya is as close as some of the other young stars in its vicinity (*e.g.* HD 98800, which may be as close as 20 pc; Zuckerman & Becklin 1993), and if the material orbiting TW Hya has a nearly face-on orientation, then it is likely one of the best young systems to examine for indications of the formation of planets.

To better understand the chemistry and physical conditions of the circumstellar molecular gas around TW Hya, we are conducting a molecular line survey of this enigmatic star with the JCMT (Kastner *et al.* 1996). To date, we have detected the J=2-1, 3-2, and 4-3 transitions of CO, J=2-1 and 3-2 transitions of ^{13}CO, J=3-2 and 4-3 transitions of HCN, and the J=4-3 transition of HCO^+. Spectra of most of these molecular lines are presented in Figure 1. Note the narrow, "wing-less" line profiles (even for the CO lines), which are unlike those typically observed toward T Tauri stars embedded in molecular clouds. The absence of clear evidence of mass outflow suggests that the molecular gas is bound, and supports the interpretation that the emission arises in a face-on disk.

The large abundances of HCN and HCO^+ (inferred from the strengths of these lines relative to ^{13}CO emission) suggest a chemistry that more closely resembles that of molecule-rich planetary nebulae and massive star formation regions than low-mass (T Tauri) star-forming cloud cores. Thus the circumstellar chemistry of TW Hya likely has deviated significantly from that of its parent cloud (although no evidence exists for the existence, past or present, of said cloud!). Since T Tauri stars are often X-ray sources, we investigated one possible mechanism for this chemical evolution, namely, X-irradiation of the circumstellar gas. Indeed, from analysis of archival ROSAT data, we find that TW Hya is a very strong X-ray source, with an X-ray flux of 3×10^{-12} ergs cm^{-2} s^{-1} — about an order of magnitude larger than the X-ray fluxes typical of T Tauri stars in nearby clouds such as Taurus. Since TW Hya is probably not very young (an age of at least 10^7 yr is suggested by the apparent dispersal of its parent molecular cloud), and hence likely is not as intrinsically luminous in X-rays as deeply cloud-embedded T Tauri stars, its unusually large X-ray flux is likely due to its proximity to Earth (see below). Even at a distance of only 30 pc, however, our calculations indicate that the flux of X-ray photons incident on its circumstellar molecular envelope is sufficient to explain the inferred overabundance of HCO^+, via reactions triggered by ionization of molecular hydrogen.

The relative intensities of the various transitions of CO and HCN suggest that the molecular emission region is rather warm (about 50 K or warmer) and dense (about 10^7 cm^{-3}). If gas-dust collisions are the dominant heating mechanism for the molecular gas — which is far from certain, given the possibility that the strong UV and/or X-ray emission from TW Hya are important for gas heating — then this relatively high gas temperature would suggest the emitting region is approximately the size of our solar system, *i.e.*, about 35 AU in radius. The intensities of the CO lines combined with beam-filling considerations then indicate that TW Hya is not likely to be much further from Earth than about 30 pc. This distance is consistent with the notion that TW Hya is at a rather advanced age for a T Tauri star; its luminosity at 30 pc is a mere 0.1 L_{sun}, *i.e.*, the main-sequence luminosity of a star of its spectral type (K7).

If this distance determination is confirmed (an accurate distance to TW Hya will soon be available from Hipparcus observations) then, at 30 pc, TW Hya would be the closest T Tauri star to Earth that is orbited by a prominent molecular disk. At this distance (and assuming that the gas is collisionally heated), the angular radius of the disk (about 1") would correspond to the radius of the orbit of Neptune. Such a disk should be marginally resolveable with the next generation of submillimeter interferometers at Mauna Kea Observatory, raising the potential for mapping out the gas distribution in a region that corresponds closely with the region occupied by the massive planets in our solar system. From these and other observations at very high resolution, TW Hya may have much more to tell us about how such planets came to be.

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The outflow(s) in LBS17 (NGC 2068)

Introduction

LBS17 is a dense cloud core which lies close to NGC 2068 in L1630. It was first identified as one of five massive cores (>200 Solar masses) by the CS J=2-1 survey of Lada, Bally & Stark (1991 — LBS). The other four are NGC 2071, HH24-26, NGC 2023 and NGC 2024 — all well-known star-forming complexes. Followup observations of a sample of LBS cores were made using the JCMT in March 1992 initially using CS J=5-4 but later switching to HCO^+ J=3-2, because the CS was so faint and we already had HCO^+ J=4-3 data on HH24-26 (Gibb & Heaton 1993).

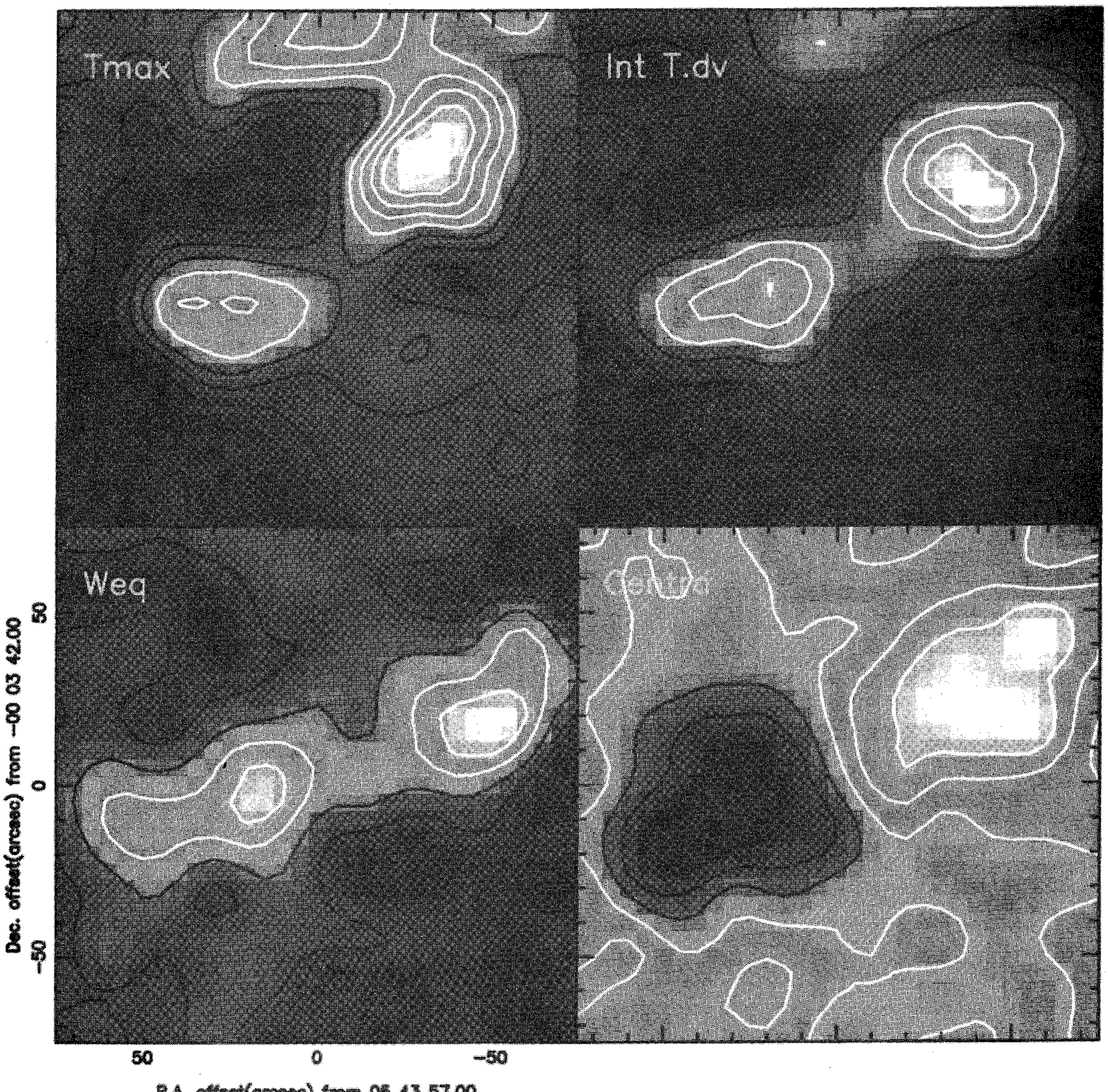

Figure 1:

Our HCO^+ map of LBS17 (Gibb *et al.* 1995) showed that the core is highly elongated — very like the ridges seen in HH24-26 and NGC 2024 — and is composed of at least eight clumps. We originally labelled these clumps B1 to B8 (roughly from north-west to south-east) for purposes of consistency, but labelling them A to H is probably more conventional. Clumps E and H stand out as the most prominent, the latter of which is also the site of a water maser (Haschick *et al.* 1983). A striking feature of LBS17 is despite its high mass and clumpy appearance, there are **no** IRAS or near-IR sources associated with the region of molecular line emission (Hodapp 1994, Launhardt *et al.* 1996).

An outflow in LBS17H?

Closer examination of the HCO^+ J=3-2 spectra revealed the presence of spatially-separated blue- and red-shifted wing emission, centred on LBS17H. Fifteen years ago, the reaction to this would have been 'A rotating disc!'; these days the reaction tends to be 'Outflow!'. The latter initially seemed a better choice, especially as the survey by Fukui (1989) revealed a CO outflow in this region (although Fukui's low spatial resolution prevented more positive association).

However, upon calculating the gas parameters and analysing the energetics it became clear that the data could still be interpreted as a rotationally supported disc. Thus (as ever!) further observations were required to try and decipher exactly what was going on. With this in mind, a service proposal was submitted and accepted. The observations were made in 1996 May — a square grid at 15" spacing of the J=3-2 line of CO, with the aim of picking up the CS J=7-6 line in the image sideband.

The four panels in Fig. 1 show the peak T_a^*, integrated intensity, equivalent width and velocity centroid over the region mapped in the velocity range 0 to 25 km/s. Black represents lowest values and white the highest. Clearly evident is the spatially bipolar distribution of the wing emission, with blue-shifted gas to the south-east and red-shifted to the north-west. This is in the same sense as the high-velocity features seen in HCO^+. The minimum at position (-20,0) is due to the presence of self-absorption at the line centre (at about 11 km/s).

The outflow has a maximum extent of 1 arcmin for each lobe (equivalent to 0.12 pc at a distance of 400 pc). There is no redshifted emission in the blue lobe and vice versa; therefore the outflow is not in the plane of the sky, but neither is it pole-on. The apparent dynamical age is low — only 10^4 years or so. If the inclination is 45 degrees then this is equal to the true age (Shu *et al.* 1991) indicating that this may be a very young object. The lack of an infrared source supports this interpretation.

The collimation is not very high, except in the map of equivalent width (lower left panel in Fig. 1). Channel maps show some evidence for a laterally-unresolved component to the flow at highest velocities and there is a weak tendency towards a 'Hubble-like' velocity distribution in the red lobe. The compact nature of this source makes it a good target for future interferometric observations.

The dense gas in LBS17H

The search for J=7-6 CS emission produced a total null result — at no position was the line detected (to a 3σ level of $T_a^* = 1$ K). For a source LSR velocity of 10 km/s, the CS line should lie at 64.6 km/s. Figure 2 shows the centre spectrum with the CO line at 10 km/s and there is clearly no significant (>3σ) emission near this velocity. The J=3-2 HCO^+ peaks strongly at the (0,0) position but is elongated with a position angle 135 degrees east of north. For comparison, the outflow has a position angle of approximately 100 degrees. Since the HCO^+ map is affected by confusion with outflowing gas, submillimetre continuum maps (using SCUBA) are clearly needed to determine the precise distribution of dense material in this clump.

Two outflows in LBS17?

Another feature is visible in Fig. 1 near (0,75) which is present across several velocity channels, suggesting that it may represent a second flow, perhaps emanating from LBS17E. Clearly, more observations are necessary to determine this! It is possible that Fukui's NGC 2068-H_2O outflow represents the superposition of two or more flows.

Summary

These maps have conclusively revealed that an outflow originates from within LBS17H. The swept-up gas is dense enough to excite the J=3-2 HCO^+ line up to 0.1 pc from the source. However, despite answering the main question of this project, the data have given rise to several more! What is the nature of the driving source? What is the real distribution of dense gas surrounding the source? Is the second outflow real? The quest continues....

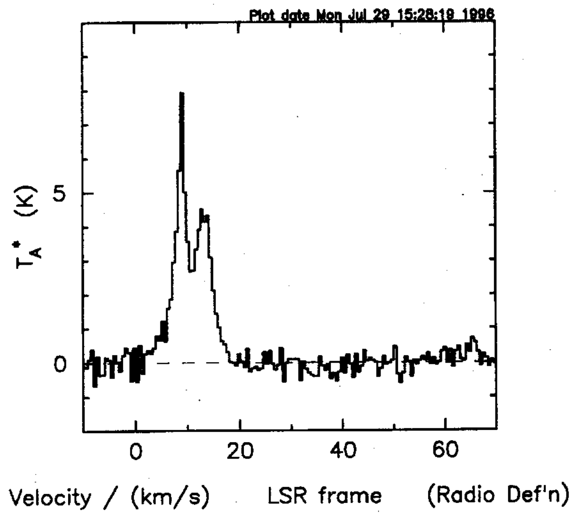

Figure 2:

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A continuum study of the NGC 2024 molecular ridge

We have been studying the properties of dust in NGC 2024 (Orion B) with the JCMT using the UKT14 bolometer. NGC 2024 is a star forming region in the Orion Molecular Cloud complex. It includes a ridge of dense molecular material containing seven compact sources (FIR cores), initially identified through their bright mm continuum emission. Some of these cores are associated with molecular outflows and probably contain protostars, while other cores show no sign of star formation and may be younger objects. The ridge is therefore an ideal location in which to investigate the effect of star formation on the properties of dust in the interstellar medium. We have obtained 800μm and 450μm continuum maps of the ridge and have reduced the data using a maximum entropy algorithm written by John Richer (DBMEM).

β variations?

Figure 1 shows a spectral index map made from the 450μm and 800μm maps. It is striking that the spectral index is lower at the positions of the FIR cores compared with the surrounding molecular cloud. This may be explained as follows: if the dust opacity is written in the usual long-wavelength form, $\kappa_\nu = \kappa_0(\nu/\nu_0)^\beta$, and the dust is optically thin, the spectral index α ($F_\nu \propto \nu^\alpha$) can be written as $\alpha = 2 + \beta + \gamma$, where γ is a Rayleigh-Jeans correction factor. An increase in α thus indicates an increase in β or γ. The typical difference in the spectral index between the ridge and the FIR cores is found to be too great to be caused by γ only, and we therefore have to conclude that variations in β are the most likely cause. In T Tauri disks β is observed to be in the range 0 to 1, which is lower than the theoretical limit for small grains ($\beta = 2$). This has been interpreted as an evolution of the dust properties, perhaps an increase in grain size, in T Tauri disks compared to the interstellar medium. In the case of NGC 2024 the decreased β in the FIR cores might also suggest an evolution of the dust properties. It is tempting to draw the conclusion that the grain particles are larger in the denser regions.

Depletion or hot dust?

In figure 2 the integrated CS(2-1) emission measured using the Owens Valley millimeter array is displayed in greyscale with 450μm continuum contours overlayed. There is a good correlation between the 450μm dust continuum and the CS(2-1) emission along the ridge, except within 7" of FIR5, where there is bright continuum but no CS emission. This discrepancy between dust and molecular line emission has been reported in previous studies, but these new data show the discrepancy to be extremely localised. It has been suggested that the discrepancy may be caused by depletion of the CS molecules onto

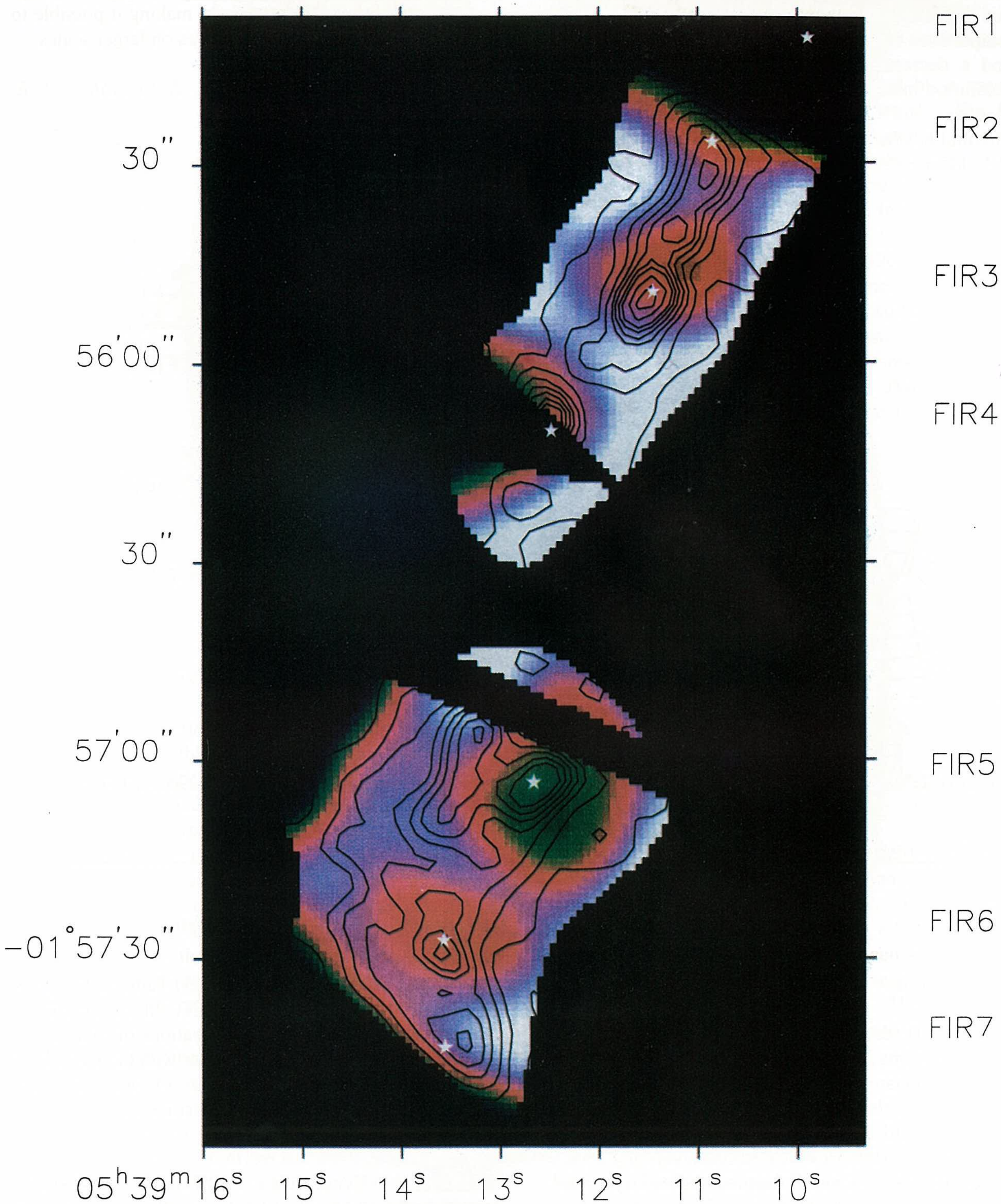

Figure 1: Spectral index map from the 450μm and 800μm continuum images. Regions were blanked in both images if the intensity was less than twice the mean rms noise in either image. The contours are from the 450μm continuum map.

cold dust grains in the dense cold condensations. An alternative explanation is that the temperature of the gas and dust in and near FIR5 is somewhat higher than in the surrounding ridge. Emission from optically thin dust scales with T_{dust}, and emission from CS scales with $1/T_{ex}$, if CS is optically thin and thermalized. At the high densities present here, T_{dust} and T_{ex} are expected to be coupled, so a higher temperature would cause an increase in dust emission and a decrease in molecular line emission. High resolution measurements at 50μm and 100μm will be essential for determining the spectral energy distributions, and hence the dust temperatures of the individual FIR cores.

With SCUBA it should be possible to observe large regions with a higher sensitivity making it possible to study variations of dust properties on larger scales.

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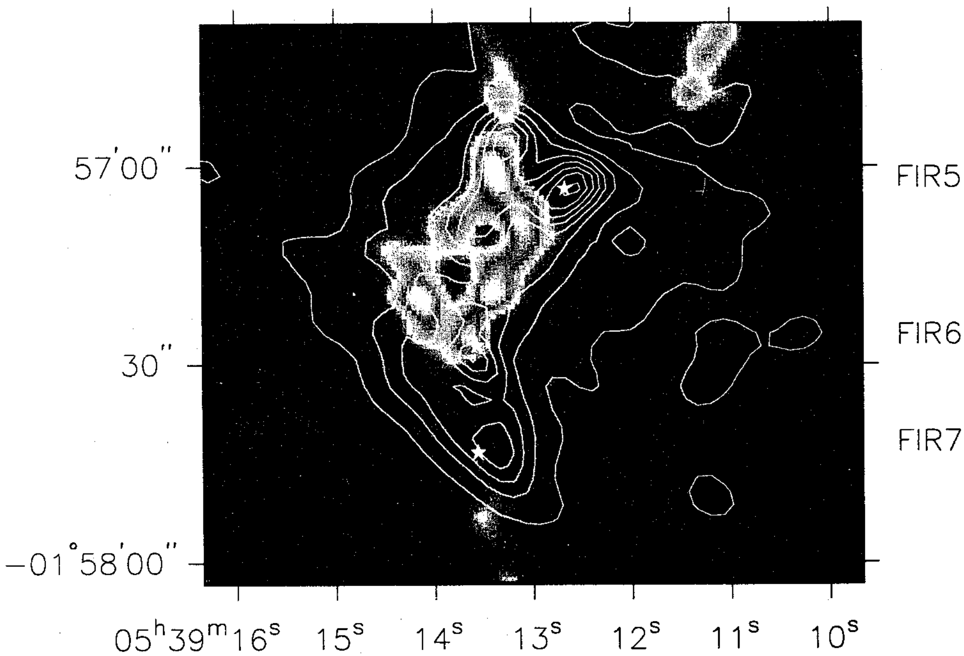

Figure 2: The grey scale plot shows integrated CS(2-1) emission (Chandler and Carlstrom, 1996, ApJ, **466**, 338), the contours are 450μm continuum emission.

Constraints on Magnetized Outflow Models of Protostars

Introduction

Magnetic fields are believed to play an important role in the collimation and driving of bipolar outflows from protostars. Polarimetric observations of star formation regions can now be used to trace the magnetic field directions, and thus test these models. Some ideal sources to observe are the youngest low-mass protostars (Class 0 sources, defined by André, Ward-Thompson & Barsony 1993), which have highly collimated and energetic flows. However, the cool protostars are only detected at far-infrared and submillimetre wavelengths, and their low flux densities present a considerable technical challenge for polarimetry. Only two Class 0 sources, VLA1623 and NGC1333-IRAS4A, have previously been detected in polarization (Holland *et al.* 1996; Minchin, Sandell & Murray 1995; Tamura, Hough & Hayashi 1995), both at the JCMT. In this article, we present our recent JCMT observations of four further Class 0 protostars, which together with the two earlier detections, represent almost all of the reasonably bright known sources (flux densities of a few Jy at 800 microns).

Our observations of IRAS16293-2422, L1448-IRS3, NGC1333-IRAS2 and HH24MMS were made in February 1995, using the Aberdeen/QMW polarimeter with UKT14. Integration times of about 1 to 2.5 hours per source were needed to detect polarization at the 1-4 % level. The directions of the magnetic fields could then be constrained to within typically ± 10 degrees.

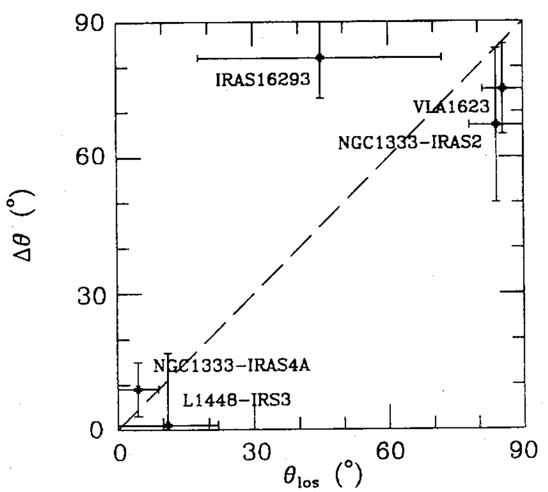

Figure 1: Correlation of $\Delta\theta$, the difference in angle between the magnetic field and outflow directions, with θ_{los}, the angle between the bipolar outflow and the line-of-sight to the observer (only the most collimated outflow system is included for IRAS16293 and NGC1333-IRAS2, both of which have secondary outflows also).

Field orientations for the protostars

Models of magnetic fields around protostars generally show a net field that is symmetric, and aligned either with the outflow, or in the perpendicular direction, along the presumed disk plane. If the outflows in the six sources share a single magnetic collimation mechanism, we might expect a single preferred orientation, such as the field always lying along the flow axis, or always along the disk plane. Surprisingly, we found instead two examples of the former, three of the latter, and one intermediate case (which was HH24MMS, a rather anomalous source with an IR jet but no well defined molecular flow).

We considered the possibility that the observed field direction might depend on the orientation of the outflow — *i.e.* the angle of inclination to the observer's line of sight. So we estimated the angle between the bipolar outflow and the line-of-sight, θ_{los}, for each source, using the method of Cabrit & Bertout (1986), which involved modelling the spatial appearance of the blue and red lobes. Figure 1 shows the results of this analysis, by plotting $\Delta\theta$ against θ_{los}, where $\Delta\theta$ is the angle between the observed field and the outflow direction (HH24MMS is omitted as the method of finding the inclination cannot be applied to the IR jet). We found that, for outflows close to the plane of the sky, the magnetic field tends to lie perpendicular to the outflow direction. In contrast, for outflows directed closer to the line-of-sight to the observer, the magnetic field tends to lie parallel to the outflow direction.

This result can in fact be explained by a viewing angle effect, as illustrated in Figure 2. The field configuration shown represents a generic class of models which typically have a circular or spiral field in or near the disk plane, and either helical or linear field lines along the outflow axis. In the first sketch, the highly ordered disk field, seen edge-on, is dominant, so θ_{los} and $\Delta\theta$ are both ~90 degrees. In the second sketch, the disk field is seen almost face-on and, as it is circularly symmetric, produces negligible polarization summed over the beam. Then only the field component along the flow is important, and θ_{los} and $\Delta\theta$ are both ~0 degrees. Thus this model reproduces the results seen in Figure 1.

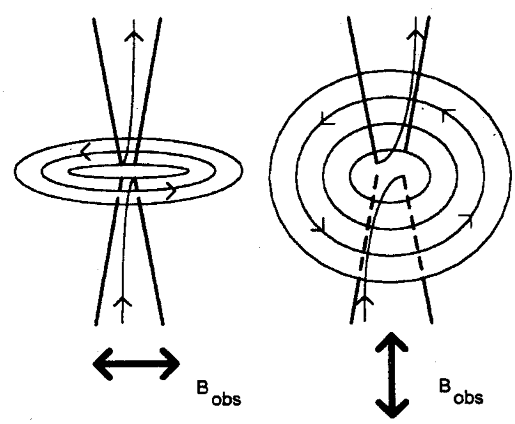

Figure 2: Sketch of magnetic field configuration which can reproduce net polarization either along the outflow axis or in the disk plane. The first sketch shows the system seen almost edge-on, and the second sketch shows the system seen almost face-on. The thin lines represent the magnetic field, and the thick lines the outflow boundary. The net observed field direction is shown below each sketch.

Evolution of the magnetic field.

The results above show for the first time that one class of magnetic models can explain the observed field orientations towards protostars. Another interesting new result is that the field evolves with protostellar age, even though all the sources are estimated to be only a few 10^4 years old. Figure 3 plots percentage polarization, *p*, for the Class 0 sources, versus the ratio $L_{bol}/L_{1.3mm}$, which is a measure of source evolutionary stage (André, Ward-Thompson & Barsony 1993). Figure 3 shows a tendency for p to decrease in the more evolved protostars (higher $L_{bol}/L_{1.3mm}$).

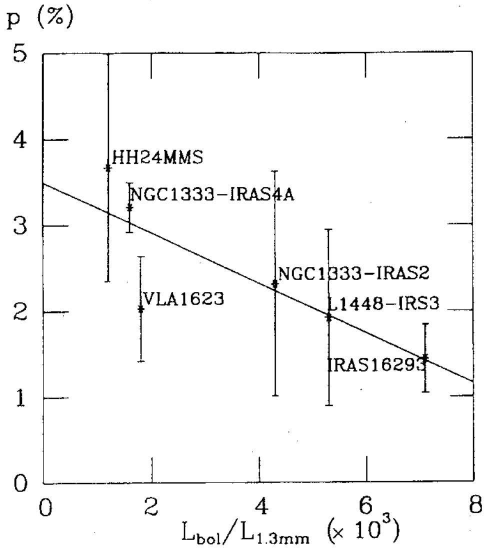

Figure 3: Correlation between p and $L_{bol}/L_{1.3mm}$, a measure of source evolutionary stage. Older protostars are observed to have a lower net polarization. The correlation is significant at the 95% confidence level.

In general, p is not related to field strength (Hildebrand 1988), and varies with field structure and grain properties in ways that are not well understood (Goodman 1996). Here, a simple interpretation of the magnitude of the polarization is offered: the field structure around the protostars may initially be very ordered, but then the field becomes progressively more disrupted as the outflow sweeps up ambient material. In a more disordered field, polarization components in different directions will tend to self-cancel, producing a lower polarization at later times, as observed. Recent observations (Bontemps *et al.* 1996) have shown that bipolar outflows evolve with time, becoming less energetic and less well collimated as they evolve. Our results show that the outflows also interact with the magnetic field, causing it to become less well ordered as the source evolves.

Conclusions

These new results imply that future models for bipolar outflow collimation will have to consider the greater tangling of the fields with time. As a follow-up, we hope to study the environments of a larger number of fainter protostars, using the next generation polarimeter in conjunction with SCUBA. We will then be able to map the magnetic field structures, and gain a much better understanding of how energetic outflows are collimated, and how they evolve and affect the magnetic field structure within their parent clouds.

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Observations of Comet Hyakutake

The past three years have been remarkable ones for cometary studies. First, in mid-1994, the fragments of comet Shoemaker-Levy 9 crashed into the atmosphere of Jupiter, leaving dark bruises visible to quite modest telescopes, and modifying the Jovian stratosphere in ways which are still evident today. Next, the bright comet C/1995 O1 (Hale-Bopp) was discovered in mid-July 1995 while still beyond the orbit of Jupiter on its way into the inner solar system. Hale-Bopp has been compared to the Great Comets of the 19th Century, and reaches perihelion on April 1, 1997. Then, while most comet-types were fascinated by Hale-Bopp, at the end of January 1996 Yuji Hyakutake discovered C/1996 B2. It quickly became clear that although this was a relatively small comet, perhaps one-tenth the mass of Halley's comet, it would more than make up for this shortcoming by making a dramatic close approach to the Earth. In fact, there are those who said that not since 1556 had there been a more favourable cometary "apparition"; the most recent contender for this title, comet West in 1976, although very bright, was a morning object which passed by rather quickly. Hyakutake's comet, on the other hand, hung in the night sky for many weeks as it approached the Earth, and in late March at close approach (which was less than 10 million miles from the Earth) stretched across the moonless late night sky with a tail visible over perhaps more than 60 degrees from Ursa Major to Coma Berenices. Many of us lost sleep just staring at it from the Saddle Road on the Big Island of Hawaii. A picture taken by Bill Dent from Hale Pohaku just before close approach shows just how bright C/1996 B2 was, hanging above the lights of Hale Pohaku and the reflected glow of Hilo.

Figure 1: Comet Hyakutake above Hale Pohaku. Photograph reproduced courtesy of Bill Dent.

Comets are interesting particularly because they are thought to be relatively pristine samples of the material from which the Sun and planets formed. Also, Hyakutake (and Hale-Bopp, as it happens) has a very long period, now estimated at perhaps around 30,000 years, suggesting that the material is less processed by repeated perihelion passages than, say, Comet Halley. Normally comets are rather faint targets for radio telescopes. But Hyakutake, by virtue of its passage close to the Earth gave an unprecedented opportunity to study the composition and development of the molecular and dust components of the cometary coma with excellent sensitivity and spatial resolution. In fact, the first detection of molecules in the coma (the J=4-3 rotational transition of HCN) was made already on February 10 at the JCMT. Subsequently, CH_3OH was first seen on February 27 and CO J=3-2 was found on March 1, both at the JCMT. Like most other telescopes, the observing schedule of the JCMT for the following months was already well in place when Hyakutake was discovered, and because of this an international consortium was put together to make target-of-opportunity observations, shoehorned into the existing schedule of the JCMT. The consortium involved people (listed at the end of this article) from

the Joint Astronomy Centre, the University of Hawaii at Manoa, and the Observatoire de Paris at Meudon.
The observing program at the JCMT focused on aspects well suited to the sub-mm capabilities of the telescope, and in areas where the data obtained could complement those from other facilities. Largely for these reasons we found ourselves observing mostly with the heterodyne receiver B3i (300 - 380 GHz), with additional observations making use of the continuum bolometer system UKT14. In the latter case, this was the last major program carried out with this venerable instrument. The observations we obtained at the JCMT fall into three groups:

a) Monitoring of the development of key molecular transitions in the coma. These were CO J=3-2 at 345.8 GHz, HCN J=4-3 at 354.5 GHz and a pair of transitions of CH_3OH $J_{kk'} = 2_{12}$-2_{01} and $J_{kk''} = 4_{12}$-4_{01} at 304.2 and 307.2 GHz. The last two transitions offered a means to determine the kinetic temperature of the coma gas from their intensity ratio. Conveniently, because of the particular configuration of the receiver, it was possible to observe these two lines simultaneously. For the same reason, it was also possible to observe the CS J=7-6 and H_2CO $J_{kk''} = 5_{15}$-4_{14} transitions in combination with CO and HCN, respectively.

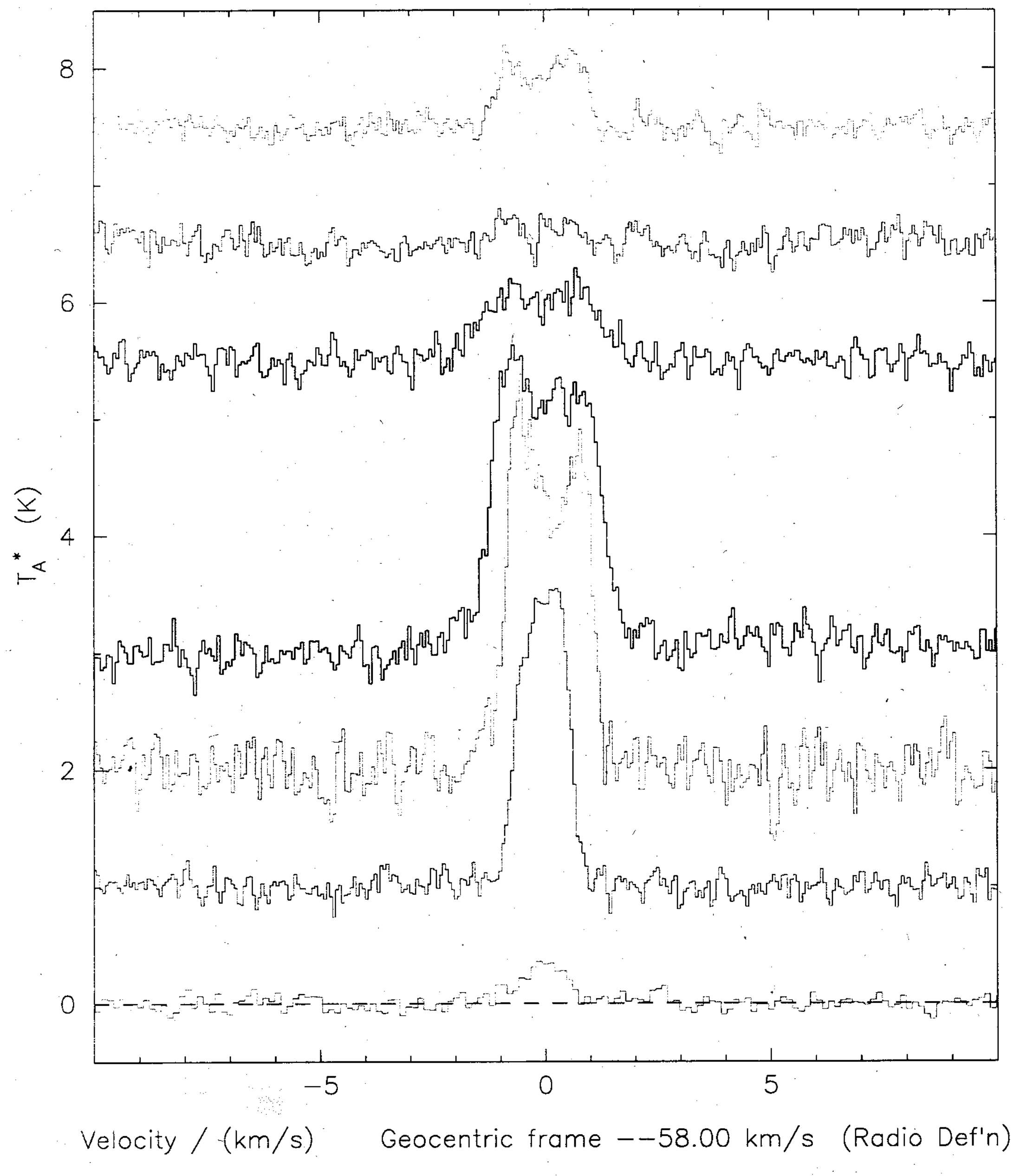

Figure 2: HCN spectra obtained as a function of time. The bottom spectrum was taken on February 10th with more recent spectra going up the figure. See text for details.

b) Searches for other species. In addition to CS and H_2CO, which were obtained "for free" as mentioned above, we made efforts to detect HNC, H_3O^+, CH_3CN and other, higher excitation, transitions of H_2CO and CH_3OH in particular.

c) Continuum observations. We were able to obtain both continuum spectra of the emission from the dust in the coma at wavelengths from 2 mm to 350 microns, as well as simple maps at 800 microns wavelength of its distribution at a time just before close approach. For comparison we obtained crude maps of the distribution of gas in the coma, using the HCN 4-3 transition.

A number of first results of this work have been published in a series of IAU Circulars, as was appropriate at the time for rapid dissemination of the information. The weightier syntheses and interpretation is now proceeding. However a couple of examples of the data obtained will illustrate the quality of the material with which we are working.

Figure 2 shows a series of HCN 4-3 spectra obtained throughout the lifetime of this program (February through June 1996; in early July Hyakutake was already far to the South and receding rapidly from Earth).

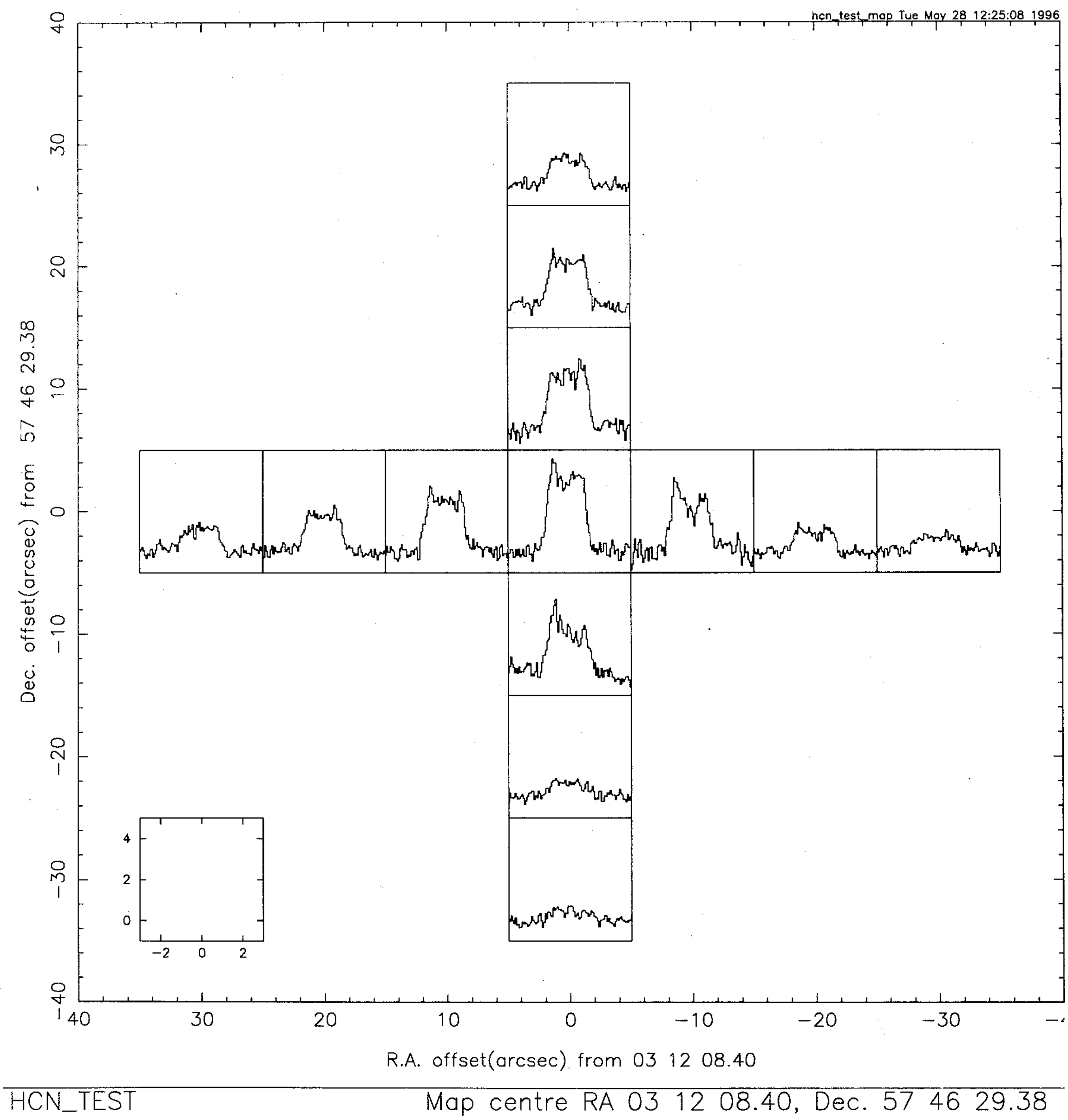

Figure 3: Map of the HCN J=4-3 emission taken just after the comet's closest approach to the Earth.

In this figure all the spectra are shown on a common velocity scale, with 0 km/sec representing the geocentric velocity of the comet at the time. All seven representative spectra are shown on a common antenna temperature scale, offset from one another by varying amounts for clarity. The earliest HCN spectrum, that of the initial discovery on February 10, is shown at the bottom. At this time, Hyakutake was about 1.85 a.u. from the Sun, approaching the Earth at a distance of 1.46 a.u. Thereafter the HCN line strength grew rapidly, the line width increased and a distinctive double-peaked structure quickly developed, as shown in the third spectrum, obtained shortly after closest Earth approach, when the comet was about 0.94 a.u. from the Sun. As Hyakutake approached the Sun, the HCN 4-3 emission became weaker, as a result of the combined effects of increasing excitation temperature and distance. The second spectrum from the top was taken a few days after perihelion (May 1); it is arguable whether anything has been detected, and at this time the orbital elements were rather poorly known. After perihelion passage, as shown in the topmost spectrum, when the comet was about 0.73 and 1.15 a.u. from the Sun and the earth respectively, the line profile once again became quite visible and maintained a double-peaked structure.

A simple preliminary map of the HCN J=4-3 emission from Hyakutake is shown in Figure 3. These data were obtained just after closest Earth approach. They show that the coma was noticeably more extended than the beamsize of 14.5 arcsec.

The spectral lines observed toward Hyakutake are the strongest ever observed in a comet, and as a result we were able, even in the limited time slots available to us, to obtain spectacular results for other molecular transitions. We detected strong H_2CO and CS, the latter for the first time in the radio/mm/sub-mm regime, and also CH_3OH. Perhaps most significantly, we also detected HNG toward Hyakutake on March 16. This was the first time HNC had been detected in a comet, and the result was subsequently confirmed at the CSO when the comet was much closer, and the transition considerably brighter. The abundance ratio of HNC with respect to HCN is typical of that of interstellar clouds with temperatures of around 40 K; the significance of this result is discussed in a paper submitted to Nature (Irvine *et al*; 1996).

In Figure 4, a continuum spectrum of Hyakutake obtained in the days before closest Earth approach is shown. This is the first high quality measurement of the continuum spectrum of any comet. The emissivity index determined from the slope of the spectrum is 0.8. Just as in the disks of pre-main sequence stars, the submillimeter continuum is due to thermal radiation from solid grains. In the case of Hyakutake, the measured emission is from about 10^6 tonnes of dust located within the central 1300 km of the coma. These dust grains have sizes ranging up to centimeters, and were formed in the proto-sun's accretion disk prior to the accumulation of the cometary nucleus. The properties of the Hyakutake spectrum, and of the grains responsible for it, may thus convey invaluable information about solar-system processes identical to those occuring in the disks of T-Tauri stars.

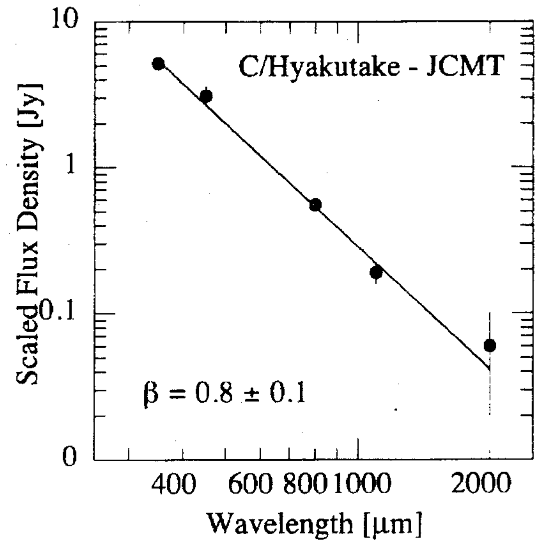

Figure 4: Continuum spectrum of the comet.

The passage of Hyakutake through the inner solar system was a dramatic curtain-raiser to the forthcoming show cautiously expected of Hale-Bopp. With the bright line and continuum emission observed towards Hyakutake, we now have a better idea of what to look for in Hale-Bopp in the sub-mm region. However, comets are notoriously fickle where expectations are concerned. Hale-Bopp, unlike Hyakutake, will not come very close to the Earth. On the other hand, it seems to be a much more active object, and this may compensate. One respect in which Hale-Bopp is better for mm/sub-mm astronomy results from the fact that the perihelion distance for it is only a little less than 1 a.u.; thus we can expect that excitation temperatures for Hale-Bopp, unlike Hyakutake, will remain in the region favourable to the production of strong lines in our wavelength band.

Throughout this campaign we were supported by the tireless efforts of Brian Marsden, Dave Tholen and Don Yeomans in the production of osculating elements and ephemerides for C/1996 B2. Their role was crucial in ensuring that the JCMT was pointed toward the correct position. This was not at all an easy task when one considers that at closest approach the comet was moving at an angular rate well in excess of 10 degrees per day. The situation was further compounded near perihelion, when non-gravitational forces conspired to modify the orbital elements at a time when the comet was essentially impossible to see.

Henry Matthews, JAC

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