

# JAMES CLERK MAXWELL TELESCOPE

## Annual Report

1999



**The James Clerk Maxwell Telescope (JCMT) facility is operated by the Joint Astronomy Centre, Hilo (JAC) on behalf of the three participating agencies:**

**The United Kingdom Particle Physics and Astronomy Research Council (PPARC)**

**The National Research Council of Canada (NRC)**

**De Nederlandse Organisatie voor Wetenschappelijk Onderzoek (NWO)**

**Front cover:**

*The James Clerk Maxwell Telescope and Carousel (photograph copyrighted to Richard Wainscoat, UH and used with permission)*

**JAMES CLERK MAXWELL TELESCOPE**

**Annual Report**

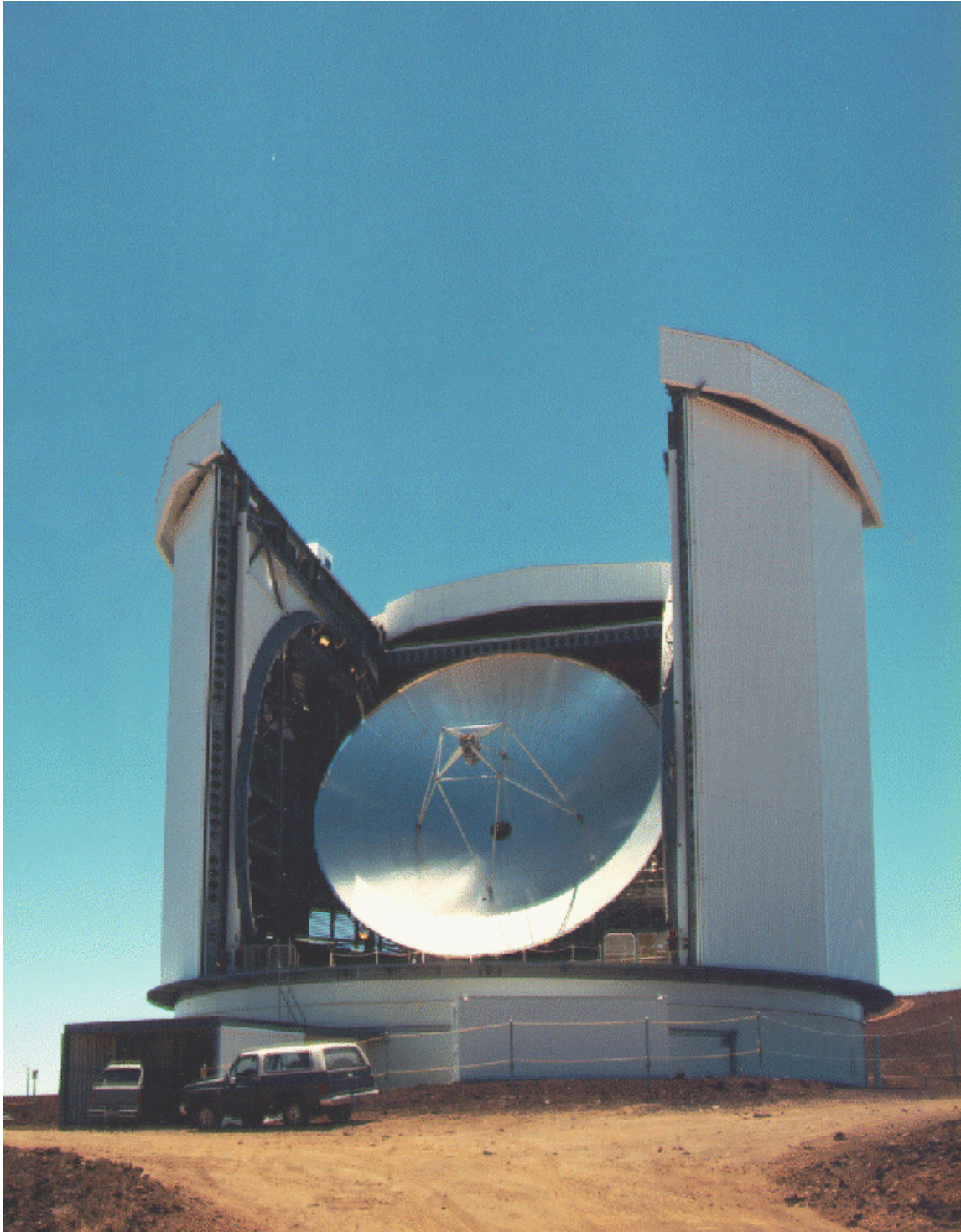
**of the**

**James Clerk Maxwell Telescope Board**

**1999**

## The JCMT Mission

*The James Clerk Maxwell Telescope, through a focus on scientific excellence, will be the most efficient and advanced ground-based submillimetre astronomical facility in the world.*



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**Frontispiece:** Top: the new central bearing housing safely installed under the main support axis of the antenna. Instrument; Bottom: SPIFI assembled on the carousel floor awaits hoisting to the Nasmyth platform.

## **Foreword**

*by Dr E. R. Seaquist, Chairman of the JCMT Board*

I am pleased to introduce the Annual Report of the James Clerk Maxwell Telescope for 1999. This has been a year which has seen not only continuing scientific successes, but which has also laid the foundations for an exciting future for the JCMT.

The report describes scientific highlights which shows that the scientific productivity of the JCMT is high. The full impact of SCUBA is now being realized as results from this instrument are dominating current research in the sub-mm continuum. Exciting progress has been made in studies of star formation and galaxy evolution in the early universe. Results from a new visiting instrument, SPIFI, have yielded an array of exciting work on C I and high excitation transitions of CO in the ISM of our own Galaxy and in nearby starburst galaxies. There have also been significant strides in the developments of instruments, instrumentation software, and engineering. In particular, the Board commends the engineering staff for the successful replacement of both the central bearing and the carousel drive motors.

The report of the international review panel was received and carefully considered by the Director and the Board. The report confirms the general direction being undertaken, and has been very helpful in providing input to the process of future planning. The report confirms the wisdom of directions undertaken, including the approval of HARP-B, support for CHAMP-D, approval of preliminary design studies for SCUBA-2, and the intention to link the JCMT with the SMA. If these projects come to fruition, and on schedule, then the JCMT will clearly remain a leading facility well into the future. The panel stressed the need to concentrate on the core programs, permitting the JCMT to focus on its major strengths. This will require consideration of new modes of operation to ensure this focus and of the means to provide the resources needed. This past year much thought and effort by the Director, his staff, and the Board have been put towards addressing this and other challenges.

As always, the successes of the JCMT are attributable in no small measure to the dedication and skills of its Director, Professor Ian Robson, and his staff. The Board joins me in thanking them all for their continuing efforts to ensure that the JCMT continues to be the world beater in its field.

## Introduction

*by Professor Ian Robson, Director of the JCMT*

The year began on a very positive note with the visit in February of the International Review Panel. Their report was presented to the JCMT Board in May and as anticipated the Panel was highly supportive of the JCMT as a facility. They also gave a very positive endorsement to the development plans that have been in place for some time. In particular the Panel was enthusiastic about a next generation SCUBA and the promise of spectroscopic array cameras. The need for expediency in delivery times, however, was highlighted. The Panel was also enthusiastic about the involvement of the JCMT with the Smithsonian Submillimetre Array, recognising the benefits to all parties that this would bring. We were encouraged to look for innovative solutions to array receivers and the best method of maximising the scientific impact of linked interferometry. In terms of operations and staffing, the Panel recognised the on-going tight level of funding for the operational requirements. In subsequent discussion at the Board in May it was suggested that one way to alleviate some of the pressure felt by all staff, but particularly the support astronomers, was to concentrate on the higher quality science at the expense of lower quality backup programmes, usually undertaken in poor weather. This was approved by the Board and, although it was controversial within some sections of the community, it nevertheless achieved its aim of alleviating a notable workload. The Panel also recognised the importance of the recent spectacular scientific results, especially from SCUBA, some of which had come from large programmes of many collaborators. They encouraged more use of these to maximise the scientific impact of the telescope. This year also highlighted the dramatic importance of the SCUBA data on two key areas of astronomy: the presence of dust disks around nearby stars and the evolution of galaxies in the early Universe. These two areas received very high levels of citations and both have made truly revolutionary inroads into their areas. The two SCUBA papers on the Hubble Deep Field area were both in the top ten citations of all physics in the USA in the third quarter of the year.

As time moves on, the brilliance of the El Nino year is brought into sharp focus. Even with flexible scheduling, there is little that can be done to complete programmes when the weather is very poor. A number of science highlights were obtained during the year and many are described in this Report. I will select just two to mention. The first is the data from the highly successful and challenging observations by the visiting instrument SPIFI, which is a 350-micron imaging Fabry-Perot interferometer. Great credit goes to members of the visiting team and staff of the JAC in getting this complex instrument operating so well on its first visit to the telescope. The second, which will be detailed in next year's Report, is the excellent progress made on the Galactic Centre survey. This is by far the most extensive submillimetre mapping project undertaken to date, a 2.5 x 0.6 arcminute image of the Galactic Centre region at 850 and 450 microns with SCUBA. The results are absolutely spectacular and were the clear highlight of the submillimetre imaging meeting in Tucson in June.

Turning to the facility, two major projects were completed during the year, both of which were highly successful. The absolute pointing of the JCMT is regularly measured and is 1.6 arcsec rms in both axes. With the advent of SCUBA, glitches of many arcseconds were very occasionally seen in the data, but were only obvious on relatively bright sources. These glitches were eventually identified with the track joints, but a full understanding took some while to determine and in the process a 10-year old design flaw in the telescope was uncovered. A simple pragmatic cure was to place 3 tonnes of weight on the front of the antenna platform! The second major facility project was the replacement of the telescope central bearing which, as noted in last year's report, had been diagnosed due to the onset of very repeatable and regular pointing

excursions of  $\pm 5$  arcseconds. These had a pitch of exactly 22 per revolution of the antenna, which clearly pointed to the central bearing itself and because the effects were so regular, they were taken out in software and the problem was transparent to users. Eventually, a failed bearing race was identified, which posed a potentially catastrophic failure mode for the telescope. The project to replace the central bearing was complex and costly. However, the engineers and technicians at the JAC did an excellent job and the bearing was replaced within the two-week downtime. A novel aspect of this was the provision of a daily web-diary and a web-camera that allowed remote inspection of the progress around the clock.

After this success, the engineering team was immediately tested again following a catastrophic failure of the drive motors of the carousel, which closed the telescope for 10 nights in June. A consultant from the manufacturers was immediately flown out and confirmed our fears; the system was now obsolete. A “tiger team” from the JCMT and UKIRT recovered the telescope into an emergency mode of operation and then effected a longer-term repair. Meanwhile, a new system was specified and ordered. This will be installed in 2000 and will achieve the long-awaited speed-up of the carousel. Overall the facility instruments had worse than expected reliability and frankly the users deserved better. Obtaining better reliability is a key target for the operations staff.

For the development projects, the new spectrometer (ACSIS) continues to be on-track. The project to link the JCMT with the Smithsonian Submillimetre Array (the SMA) has slowed a little mainly due to pressure on the SMA. The upgrade of SCUBA with the installation of the new blocking and wider-band 850 and 450 micron filters was undertaken in September and these have produced significant gains in performance, especially at 450 microns where the gain is around 45%. Unfortunately, subsequent problems with the filter drum have meant that it has been expedient to operate in a fixed filter mode for the remainder of the year. This has had little impact on the vast majority of the programmes. Software projects suffered markedly during the year, which resulted in a thorough review by the new Head of JAC Software and Computer Systems of the available effort and skill level, the day-to-day operational requirements (vastly underestimated) and the planned project work. Subsequently, some projects were delayed to ensure completion of others.

The November Board meeting focused on the new instrument programme and in preparation for this the community was widely consulted. The results were fed into the Board through the JCMT Advisory Panel, which met in Amsterdam. Strong endorsement was given to HARP-B, the 16-channel spectroscopic camera operating at 345 GHz (850 microns) which the Board subsequently approved. Although a very successful CoDR had been held for HARP-B in March the resulting staff effort requirement and length of build had been increased over that expected and a suitably revised plan was produced for November. HARP-B will be delivered in 2003. The possibility of a wide-field continuum capability to succeed SCUBA was easily top of the wish list from the community and the Board approved funding for a preliminary design study. This instrument, called SCUBA-2, is envisaged to cover an 8 arcminute diameter field-of-view, to operate at two wavebands (probably 850 and 450 micron), to have as good a pixel sensitivity as an upgraded SCUBA, to have no moving parts, and to employ the next generation detectors with bare pixels (no feedhorns). This will make it effectively the first submillimetre CCD. The high-frequency heterodyne camera, CHAMP-D, was also supported and the project consortium was requested to bring back a proposal to the May 2000 Board meeting. This instrument is proposed by a collaboration between SRON and MPIfR and is a D-band (600 GHz – 450 micron) version of the current CHAMP camera. It is expected to be available on the JCMT for 2 or four years. This suite of instruments will maintain the JCMT at the forefront of submillimetre science for the rest of the decade.

In November the JCMT Board made other pronouncements on policy issues regarding 'large' observing programmes; rules regarding release of data from the archive; and guaranteed time for instrument builders. These were also guided by input from the user community and the full text of the announcements was given in a note to users in January.

Staff retention continued to be a problem for the JCMT as did recruitment. The latter now seems to be a common problem for the facilities on Mauna Kea apart from recruiting from each other. Key resignations included the JCMT Telescope Manager, which caused extensive re-organisation of the JAC software management. Recruitment action for the vacant position was very successful. Staff shortages due to recruitment problems remain one of the major problems in terms of getting on top of all the items in the engineering wish lists and development projects.

The year turned out to be eventful in terms of distinguished visitors. The dedication of Gemini North saw a visit to the Joint Astronomy Centre in Hilo and the JCMT by HRH Prince Andrew. The Chief Executive of PPARC and Council Members also visited the JAC and telescopes. Later in the year the Chairman of PPARC toured the telescopes and the JAC. Suffice to say that all were impressed with what they saw.

In summary, the JCMT has had a very good year with some excellent scientific results and some spectacular work by the engineering support teams. While all is not perfect, and improvements will be made, especially in the reliability of the instrument suite, nevertheless, given the overall level of resources, this is a very satisfactory performance and I am most grateful to all those who worked so hard to achieve this.

# **1. The James Clerk Maxwell Telescope Facility**

## **1.1 Introduction**

Situated at an altitude of 4092 m close to the summit of Mauna Kea, Hawaii, the 15-metre James Clerk Maxwell Telescope is the largest facility in the world designed specifically to operate in the submillimetre region of the spectrum. It is operated by the United Kingdom, Canada and the Netherlands (the 'Partner Countries') on behalf of astronomers worldwide. It is managed by the PPARC's Joint Astronomy Centre (JAC) in Hilo, Hawaii. The JAC is also responsible for the operation of the United Kingdom Infrared Telescope (UKIRT).

Development and operation of the JCMT is overseen by the JCMT Board.

## **1.2 Telescope**

The 15-metre diameter primary reflector of the JCMT is made up of 276 individual lightweight panels. Each panel consists of a thin aluminium skin bonded to an aluminium honeycomb and is attached at three points to the backing structure of the antenna. The alignment of the mechanical panels can be adjusted by means of stepper motors at the mounting points. The backing structure is designed to maintain a parabolic figure as gravity distorts the antenna as it tips to different elevations. The surface accuracy is routinely measured and adjustments required to each panel are calculated by making observations of a coherent millimetre source located on top of the UKIRT building or by utilizing the in- and out-of-focus images of a bright planet. The sub-reflector or secondary mirror can be adjusted in three axes to compensate for changes in focus as well as changes in the figure of the primary. In addition, the secondary can be tilted or chopped in two axes in order to perform sky background cancellation.

## **1.3 Carousel**

The JCMT carousel co-rotates with the antenna and is designed to protect the telescope from the elements and to provide a safe and comfortable working environment for astronomers and engineers. An important feature of the carousel is the membrane which is deployed in front of the antenna at all times and is transparent at millimetre and submillimetre wavelengths. In addition to providing protection from the wind, the membrane performs the useful function of reflecting the visible and near-infrared radiation, providing protection from the solar 'heat' which could damage the antenna, thereby allowing daytime astronomical observations including direct observations of the Sun itself.

## **1.4 Instruments**

Receivers for the telescope can be located either in one of the bays of the Cassegrain cabin or on the two Nasmyth platforms located at the ends of the elevation bearing.

A number of receivers can be and are accommodated on the telescope at the same time and are selected by a movable tertiary mirror located in the centre of the Cassegrain cabin. The heterodyne receivers, covering the atmospheric windows between 215 and 680 GHz, are mounted in the cabin while the continuum bolometer array instrument, SCUBA, occupies one of the Nasmyth platforms.

## **1.5 Tripartite Agreement**

Under the terms of the Tripartite Agreement, the partner countries jointly undertake the operation, maintenance and development of the facility with the resources provided for this purpose in the proportion UK: 55%, Canada: 25% and the Netherlands: 20%. In accordance with the Operating and Site Development Agreement, 10% of the total observing time is set aside for use by the University of Hawaii (UH).

The JCMT Development Fund provides resources for the development of state-of-the-art instrumentation and for enhancing the capability of the JCMT.

## **1.6 Time Allocation**

All observing time, except UH, is allocated by the Panel for the Allocation of Telescope Time (PATT) on the basis of scientific merit and technical feasibility. Use of the telescope is not restricted to applicants from partner countries. National Time Allocation Groups (TAGs) referee, assess and nominate allocations for applications from their own countries. These time allocations are later combined and awarded by an International Time Allocation Committee (ITAC). Applications from outside the partner countries are assessed and nominated by the ITAC. The ITAC is composed of the Chairs of the national TAGs and is a sub-committee of the PATT.

## **1.7 The JCMT Board**

The international partners set up the James Clerk Maxwell Telescope Board to oversee the operation of the JCMT, to foster and develop collaboration between their astronomers in the use of the facility, and to endeavour to maintain the JCMT in the forefront of world astronomy. In particular, the JCMT Board (i) oversees the development of the facility; (ii) determines (with the advice of users and of the Director JCMT) the programme of operation and maintenance of the facility; (iii) approves annual budgets and forward estimates, and (iv) determines the arrangements for the allocation of observing time.

The JCMT Board comprises four persons appointed by the PPARC, two appointed by the NRC, two appointed by the NWO, and one appointed by the University of Hawaii. Two meetings of the JCMT Board were held in 1999, on May 25 & 26 at the UKATC in Edinburgh, Scotland and on November 18 & 19 at the JAC in Hilo, Hawaii.

## **1.8 The JCMT Advisory Panel**

The JCMT Board has set up the JCMT Advisory Panel to advise it and the Director on the scientific operation and development of the facility. This Panel met twice in 1999, on May 18 via telephone conference call and on November 8 & 9 at the Astronomical Institute in Amsterdam, Netherlands.

## 2. Scientific Report

### 2.1 The (peculiar) composition of Comet Lee

Three comets, C/1998 M5 (LINEAR), 10P/Tempel 2 and C/1999 H1 (Lee) have been detected through at least one rotational line at JCMT in 1999. The new comet C/1999 H1 (Lee) was the brightest and most interesting target of these last 2 years. It reached a visual magnitude of 6.5 in June-July 1999 and was at perihelion at 0.71 AU from the Sun on July 16. It was readily detected at the beginning of May, a mere three weeks after initial discovery by the Nançay Radiotelescope, which monitored the OH radical, and subsequent observations with the SEST in Chile (which monitored HCN and CH<sub>3</sub>OH lines).

Since the comet appeared enriched in methanol from the first observations, a target-of-opportunity program was put in place to enable observations as early as mid-May. In addition, early evening observations with the A-band heterodyne receiver, and daytime afternoon observations took place in early June, late August, and early September.

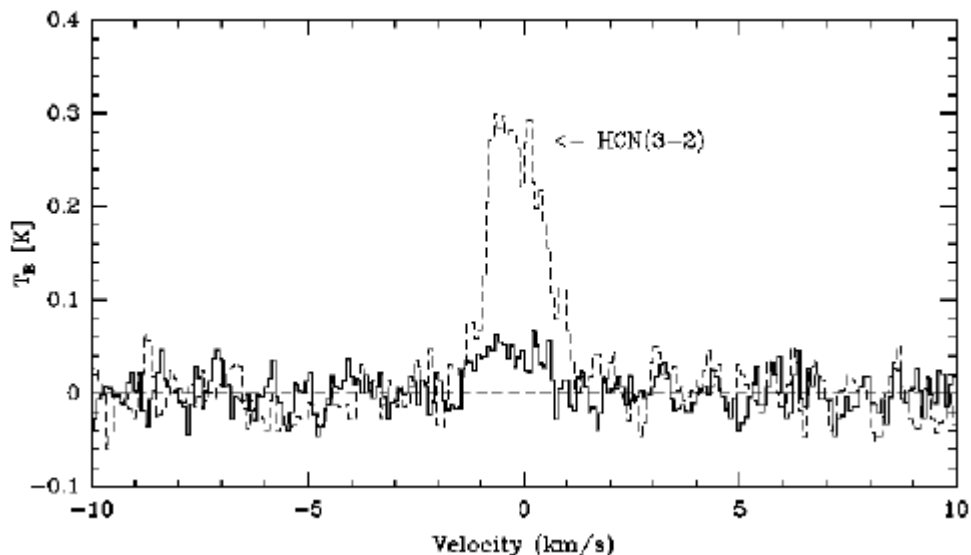
JCMT observations of comet Lee by *Biver (University of Hawaii)*, covering a 137-day period, contributed significantly to a world-wide campaign, involving the SEST, CSO, IRAM 30-m and Nançay telescopes. This was actually the second longest monitoring of a comet at radio-wavelengths, after Hale-Bopp. Comet Hyakutake was detected at the JCMT over a 127-day campaign in 1996 (Biver et al., *Astron.J.*, **118**, 1850, 1999).

Molecular species, HCN, CH<sub>3</sub>OH, H<sub>2</sub>CO, CS, HNC and CO were all searched for in comet Lee with the JCMT, but only HCN, HNC and CO lines were detected. CO was marginally detected at 345 GHz, at which frequency it is 3 times easier to detect than at 230 GHz. The maximum of activity was reached at the end of June 1999, with a water out-gassing rate larger than  $1.5 \times 10^{29}$  molecules per second. The abundances of these species relative to water are estimated to range from 0.012% (HNC), 0.10% (HCN), 1.3% (H<sub>2</sub>CO), to 3.9% (CH<sub>3</sub>OH), and about 4% for CO. The H<sub>2</sub>CO and CH<sub>3</sub>OH data are from CSO observations.

One of the most surprising results was the detection of an HNC/HCN mixing ratio of 12% (June 6-7 observations at JCMT, see Figure 1 and also IAU Circular 7203). Comet C/1999 H1 (Lee) is a long period comet like Hale-Bopp and Hyakutake, but it has much lower activity (1/100th of Hale-Bopp, 1/3rd of Hyakutake at the same heliocentric distance). The observed abundance of HNC is, however, comparable to that in Hale-Bopp and twice the value inferred in Hyakutake. Chemical modeling has suggested that HNC could be a product of coma chemistry in a highly active comet like Hale-Bopp, but this detection in a moderately active comet should provide further constraints on the origin of HNC in comets.

Another interesting comparison amongst these 3 comets, which seem to have a similar origin (long-period high inclination orbit), is the value of the ratio of the CO to CH<sub>3</sub>OH (from CSO data) out-gassing rates. The abundance ratio of CO/CH<sub>3</sub>OH was around 13 and 9 in comets Hyakutake and Hale-Bopp respectively. However, it is a least one order of magnitude lower (about 1) in comet Lee. This indicates a relative depletion in a very volatile molecule like CO (but not H<sub>2</sub>CO) and an enrichment in methanol (twice as abundant as in these other comets).

Early results have been presented at the Asteroids, Comets, Meteors meeting in Ithaca, NY, July 26-30, 1999 and at the Division for Planetary Sciences meeting in Padova, Italy, Oct. 10-15, 1999 (Bockelée-Morvan et al., *B.A.A.S.*, **31-4**, 1097, 1999). In parallel, molecular lines were also detected in the UV and Infrared (e.g. Weaver et al., *B.A.A.S.*, **31-4**, 1123, 1999).



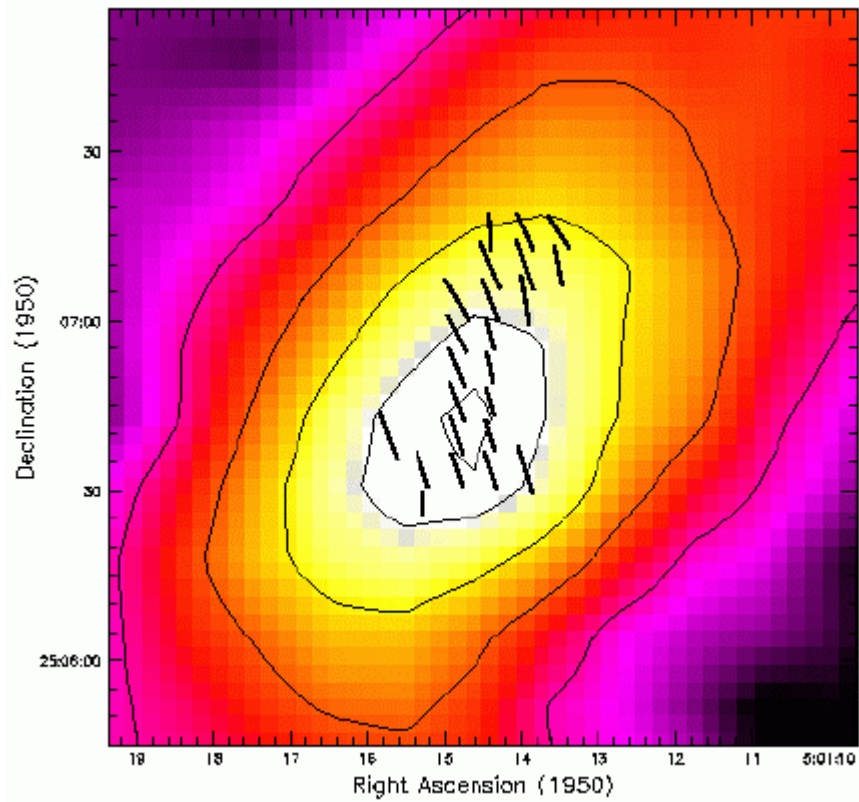
**Figure 1:** Averages of the spectra of HNC(3-2) at 272 GHz and HCN(3-2) at 266 GHz (dashed lines) in comet C/1999 H1 (Lee) obtained at JCMT on June 6 and 7, 1999. The spectra are shown at the same scales, intensity being in Kelvin in main beam scale (corrected for beam efficiency). The velocity relative to the comet nucleus is given on the horizontal axis in km/s (The spectral/velocity channel spacing is 78.1kHz/0.086km/s (HNC) to 0.088km/s (HCN)).

## 2.2 Magnetic field geometry in pre-stellar cores

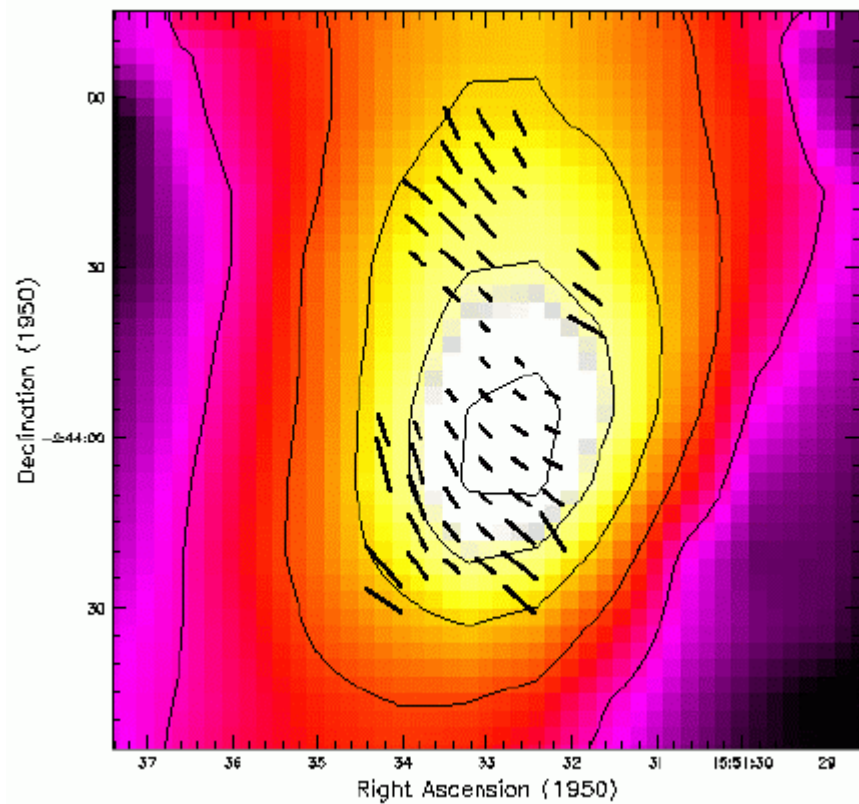
Magnetic fields play an important role in the formation and evolution of molecular clouds and in the process by which stars are formed. In magnetically dominated models, clouds form by material streaming along field lines, so that the structures formed are elongated preferentially perpendicular to the magnetic field (e.g. Ciolek & Mouschovias 1994, *Astrophys. J.*, **425**, 142). The cores then evolve by the process of ambipolar diffusion, in which the neutral gas diffuses through the ionised component, which is held static by the magnetic field. Observations of the geometry of molecular clouds should allow one to test the geometrical predictions of these models. Myers and co-workers (e.g. Benson & Myers 1989, *Astrophys. J. Suppl.*, **71**, 89) identified a large number of ammonia cores, which were shown to be sites of low-mass star formation. Ward-Thompson et al. (1994, *M.N.R.A.S.*, **268**, 276) observed the submillimetre continuum emission from the 'starless' cores (those without IRAS sources) and named the most centrally condensed objects 'pre-protostellar' (or 'pre-stellar' for short) cores. They found that their density profiles roughly matched the predicted profiles of ambipolar diffusion models. Observing the magnetic fields in these cores was necessary to further test these models.

Ward-Thompson (Cardiff, UK) has used SCUBA in conjunction with the polarimeter, in the 16-position jiggling mode to produce a fully sampled 2.3 arcminute image of each core, two of which are shown in Figure 2. In each case the Stokes I map of dust emission is shown with contours overlaid. The direction of the magnetic (B-) field in the plane of the sky is shown by a series of vectors that are perpendicular to the direction of the polarization observed, in accord with the usual Davis-Greenstein assumptions, and the length of each B-vector is proportional to the percentage polarization. The first image shows the L1544 pre-stellar core, whose minor axis lies at a position angle of  $52^\circ \pm 5^\circ$  (all angles are measured north through east).

### L1544 — 850 $\mu\text{m}$ B-field



### L183 — 850 $\mu\text{m}$ B-field



**Figure 2:** Dust continuum emission at 850  $\mu\text{m}$  from the L1544 and L183 pre-stellar cores. The Stokes I maps are shown with the inferred direction of the B-field in the plane of the sky overlaid as a series of vectors (perpendicular to the direction of the polarization observed). The length of each B-vector is proportional to the percentage polarization, such that a vector of length 1 arcsecond represents a percentage polarization of 1%.

The weighted mean position angle of the magnetic field is  $23^\circ \pm 2^\circ$ , implying that the field direction is not along the minor axis of the core, but at an angle of  $29^\circ \pm 7^\circ$  to it. The second image shows the L183 pre-stellar core and its inferred B-field vectors in the same way. This time the minor axis is at a position angle of  $80^\circ \pm 5^\circ$ . The weighted mean position angle of the magnetic field is  $46^\circ \pm 2^\circ$ , at an angle  $34^\circ \pm 7^\circ$  to it, very similar to the situation observed in L1544.

The offset that we see in these cores between the magnetic field direction and the core elongation is not predicted by simple ambipolar diffusion models, but may be explained by turbulent MHD models (e.g. Ostriker et al. 1999, *Astrophys. J.*, **513**, 259). However, these latter models struggle to explain the very sharp-edged geometry seen in ISOCAM absorption images of pre-stellar cores (Bacmann et al. 2000, *Astron. Astrophys.*, in press). Hence, our comparison of observations and theoretical results leads us to conclude that no current model of magnetically regulated star formation can apparently account for all of the existing observations. For a full description of this work, see: Ward-Thompson, Kirk, Crutcher, Greaves, Holland & André, 2000, *Astrophys. J.*, submitted.

### 2.3 Protoplanetary accretion

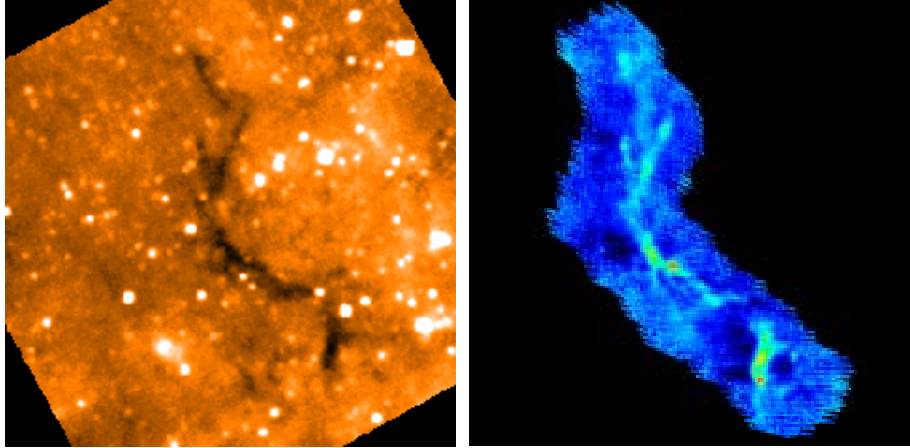
The TW Hydra association represents the nearest known region of recent star formation (Kastner et al. 1997, *Science*, **277**, 67). As a result of its proximity, this association has become a rich source of information concerning the properties and evolution of protoplanetary accretion disks around Sun-like stars. During fall and winter of 1999, *Weintraub (Vanderbilt Univ.)*, *Kastner (MIT)* & *Zuckerman (UCLA)* conducted a JCMT program designed to measure disk gas masses (or gas mass upper limits) for TW Hydra association members, via high-sensitivity measurements of CO line strengths. Such material represents the raw material out of which Jovian planets could form or the material left over after they have formed. Preliminary results indicate that TW Hydra association stars typically possess less than 10 Earth masses (or 1/30 of a Jupiter mass) of circumstellar molecular gas. Given the age of the TW Hydra association — about 10 million years — the apparent lack of molecules around these stars provides stringent constraints on the time it takes Jupiter-like planets to emerge from the residual gas around Sun-like stars.

### 2.4 Dust in infrared dark clouds

*Redman and Feldman (NRC Canada)*, *Carey (Boston College)* and *Egan (AFRL)* observed dust and gas in a selection of infrared dark clouds detected by the Mid-course Space Experiment (MSX) satellite. These clouds are identified by their substantial mid-infrared (8-25  $\mu\text{m}$ ) extinctions in MSX Galactic Plane survey images (Egan et al., *Astrophys. J.*, **494**, L199, 1998). From their high mid-infrared opacities and lack of emission between 8 and 100  $\mu\text{m}$ , Egan *et al.* concluded that the infrared dark clouds exhibit hundreds of magnitudes of visual extinction, contain large column densities of cold dust, and are dense molecular cores.

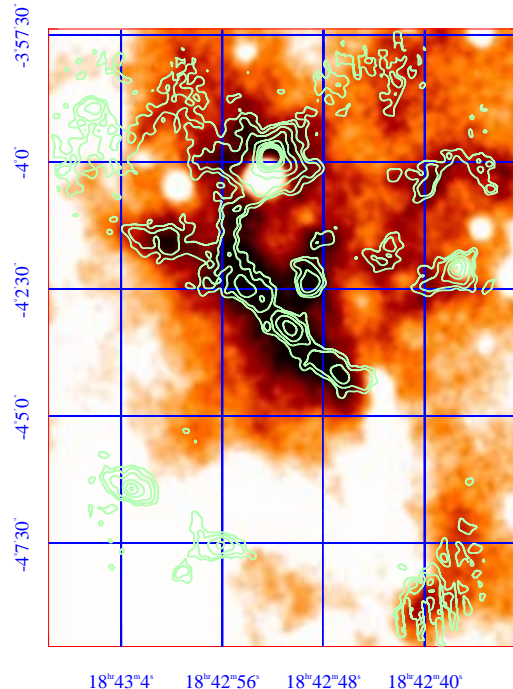
Subsequent observations (Carey et al., *Astrophys. J.*, **508**, 721, 1998) of millimeter transitions of  $\text{H}_2\text{CO}$  toward ten infrared dark clouds confirmed that these objects contain dense molecular gas. Large Velocity Gradient (LVG) modeling of several transitions of  $\text{H}_2\text{CO}$  indicate that infrared dark clouds have kinetic temperatures of 10-20 K,  $\text{H}_2$  number densities  $\geq 10^6 \text{ cm}^{-3}$ , and molecular hydrogen ( $\text{H}_2$ ) column densities ranging up to  $10^{23} \text{ cm}^{-2}$ . The available data strongly suggest that the gas and dust are in thermal equilibrium.

SCUBA was used to map a number of infrared dark clouds and revealed filamentary/flocculent clouds in emission at 850 and 450  $\mu\text{m}$ , with bright, compact sources along the filaments. Many of these compact sources are prolate, extending along the direction of the filament. These cores appear to be in a variety of early stages of star formation. Some of them contain bright infrared sources, while others are completely dark in the MSX 8  $\mu\text{m}$  images, suggesting that they are Class 0 or earlier. In addition, molecular line data taken with receivers RxA3 and RxB3 show evidence for outflow from all of the cores observed, and for infall in several cases.



**Figure 3:** Images of G11.11-0.12 at 8  $\mu\text{m}$  (left) and 850  $\mu\text{m}$  (right) shown at approximately the same scale.

The SCUBA polarimeter was also used to observe several bright filamentary regions; all showed high degrees of linear polarization. The magnetic fields derived from the polarization vectors tend to run along the filaments except near the brightest compact sources where the fields often switch direction to be perpendicular to the filaments. The observed high-percentage polarization and large-scale organization of the linear polarization imply that magnetic fields in the filaments are well organized on the 14 arcsecond scale of the SCUBA beamsize at 850  $\mu\text{m}$ .



**Figure 4:** MSX 8  $\mu\text{m}$  image of G28.34+0.06 with the SCUBA 850  $\mu\text{m}$  contours overlaid.

From the molecular line and SCUBA observations, the estimated masses of the infrared dark clouds are comparable to those of the largest star-forming cores. The individual compact sources have masses that range from tens to hundreds of solar masses. It is interesting to note that the bright IRAS source 18402-0403, immediately adjacent to the bright SCUBA source P2 in G28.34+0.06, has a bolometric luminosity of about  $10^3$  suns. If this luminosity is due to accretion onto a protostar, the central mass would be that of a typical OB star. It is plausible that massive infrared dark clouds may be sites where high-mass star formation is occurring.

These results were presented at the 33<sup>rd</sup> ESLAB Symposium, "Star Formation from the Small to the Large Scale" and are in press in the Proceedings (eds. F. Favata, A. A. Kaas, and A. Wilson).

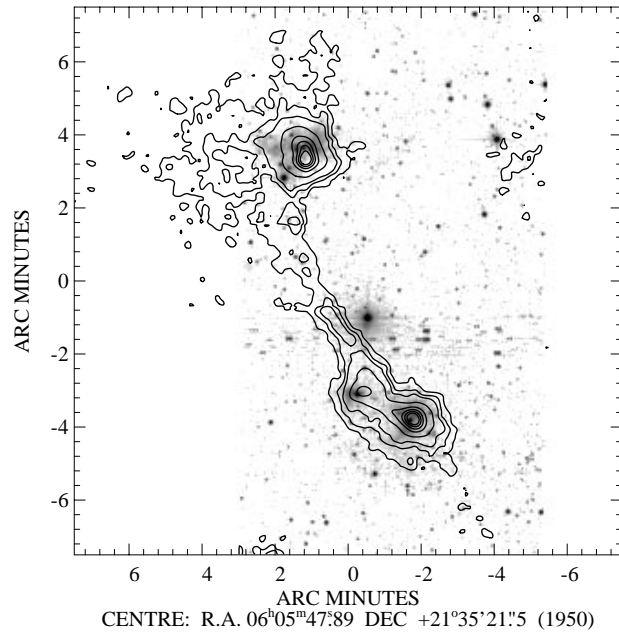
## 2.5 Millimetre emission from massive star-forming regions

*Henning, Schreyer, Klein (AIU, Jena)* in collaboration with *Waters (Amsterdam)* have investigated massive star-forming regions selected as bright and cold IRAS sources. One goal of this project has been to find massive stars in their earliest evolutionary stages and to define an evolutionary sequence for such objects.

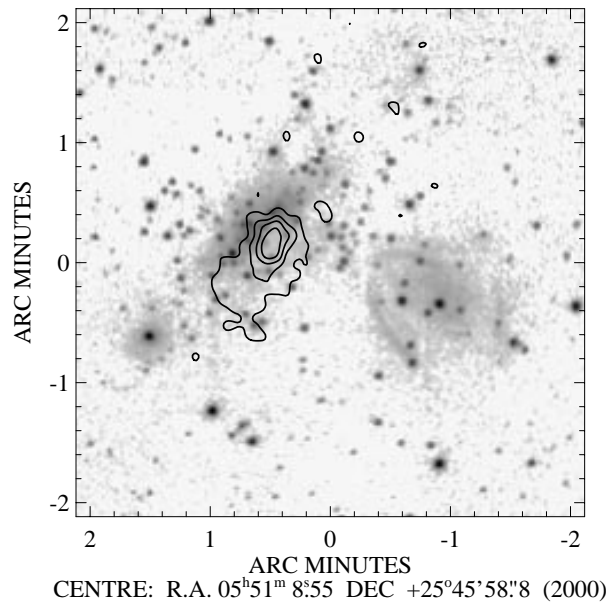
Whether massive OB stars form via coalescence or disk accretion is not yet known. The importance of spontaneous versus triggered star formation is another open problem. Massive OB stars form from dense molecular cloud cores and remain surrounded by gas and opaque dust envelopes during almost their entire pre-main-sequence evolution. The dust particles in the vicinity of the very young stars are heated by the stellar radiation and re-emit the absorbed energy at infrared and submillimetre wavelengths. To the observer, these objects are thus revealed as the most luminous far-infrared sources in the galaxy. To derive the general properties of this class of objects and to find out evolutionary trends, the statistical analysis of observational data of an extended sample of objects has proven to be very useful.

In order to compile a catalogue of massive young stellar object candidates, they have searched the complete IRAS Point Source Catalog in Right Ascension from 0 to 12h (to exclude the region near the Galactic Centre) and from 30 to 90 degrees in declination. Only objects with flux densities greater than 500 Jy (flux quality  $\geq 2$ ) at 100  $\mu\text{m}$  were included. Excluding those objects that are associated with galaxies, 67 objects were identified for further observation. These sources generally display signs of massive star formation as H<sub>2</sub>O masers and outflows originating from dense cloud cores. Previous near-infrared studies of some of the regions show that almost 100% of these sources are associated with stellar clusters mostly containing deeply embedded massive stars. Furthermore, there is evidence for ultracompact H II regions associated with some of the targets from 3.6 cm VLA data.

*Schreyer and Klein* have obtained submillimetre continuum maps of 23 objects from the above mentioned sample using SCUBA at 850 and 450  $\mu\text{m}$  at the JCMT and using the 1.3 mm bolometer array at the IRAM 30 m telescope. They also obtained near-infrared images with the Calar Alto telescopes with the aim to study the stellar content of these massive star-forming regions. This study led to the detection of dense stellar clusters in all sources that have been observed. The relationship between the detected clusters and the cloud cores, traced by the submillimetre continuum radiation, is especially remarkable. The two cloud cores associated with IRAS 06056+2131 and IRAS 06058+2138 indicate evidence of tidal interaction being linked by a band of cloud material. Another possibility for such a band is the fragmentation of a larger cloud forming a filament between the two cores. In these two cases the clusters are at the position of the cloud core.

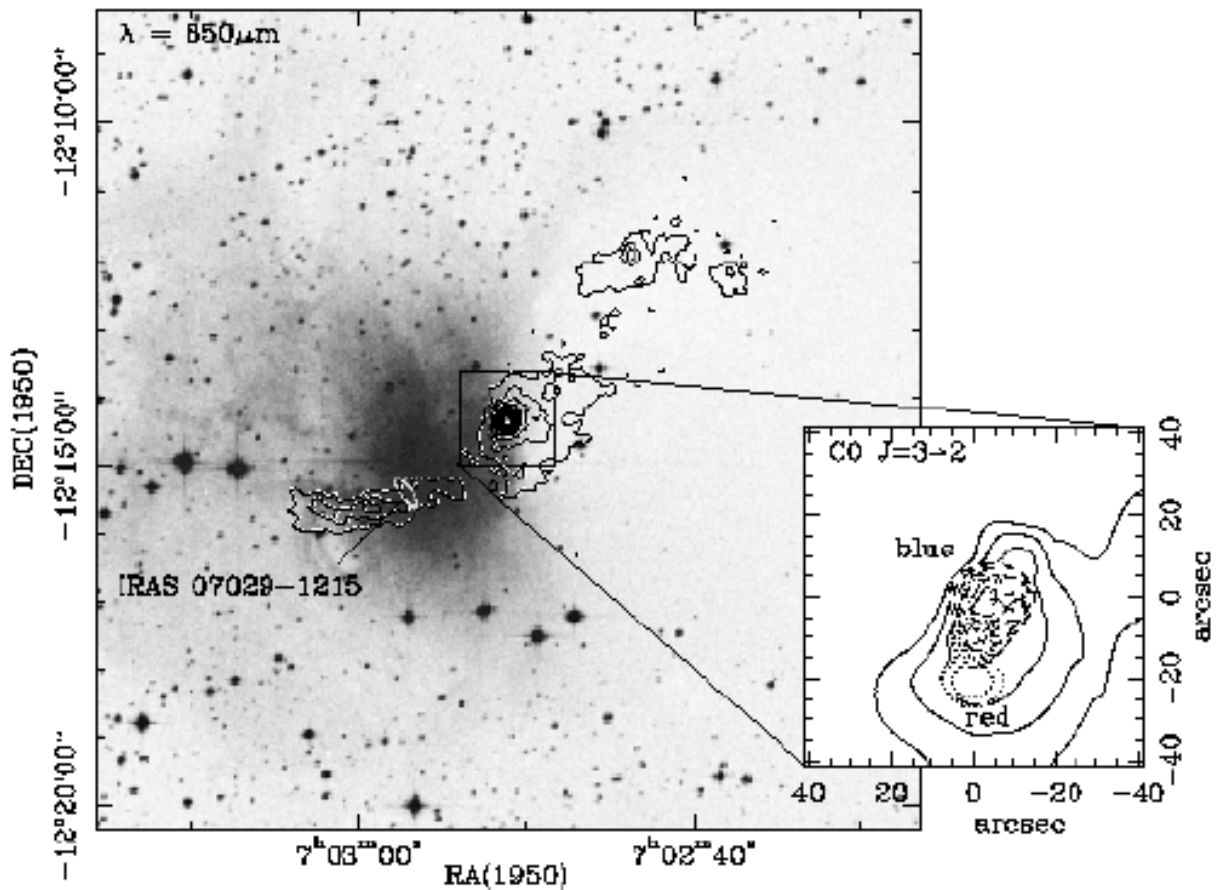


**Figure 5:** IRAS 06056+2131 and IRAS 06058+2138: The contours show the 850  $\mu\text{m}$  map obtained with SCUBA overlaid on a near-infrared image (K-band) retrieved from 2MASS. The 850  $\mu\text{m}$  map shows the band of cloud material linking the two cloud cores.



**Figure 6:** IRAS 05480+2544: The contours show the 850  $\mu\text{m}$  map obtained with SCUBA overlaid on a near-infrared image (K-band) obtained at the Calar Alto observatory. The cluster is just emerging from the cloud core.

In another source (IRAS 05480+2544) the cluster is just emerging from the cloud core. In other examples, the clusters of massive stars are too deeply embedded to be prominent in the near-infrared. These objects are presumably the younger massive star-forming regions. Two of the 23 objects were also mapped in CO (3-2), one of which, IRAS 07029-1215, is shown in figure 7. It was found that these sources are associated with energetic molecular outflows.



**Figure 7:** IRAS 07029-1215: The contours show the 850  $\mu\text{m}$  map obtained with SCUBA at the JCMT overlaid on an optical image from the Digital Sky Survey. The inset shows the CO (3-2) map also obtained with the JCMT. The lines clearly display line wings indicating the outflow.

## 2.6 Scientific highlights with SPIFI on the JCMT

The South Pole Imaging Fabry-Perot Interferometer (SPIFI) is a direct detection imaging spectrometer designed for use on the 15-m JCMT and on the 1.7-m AST/RO at the South Pole in the 350 and 450  $\mu\text{m}$  submillimeter windows.

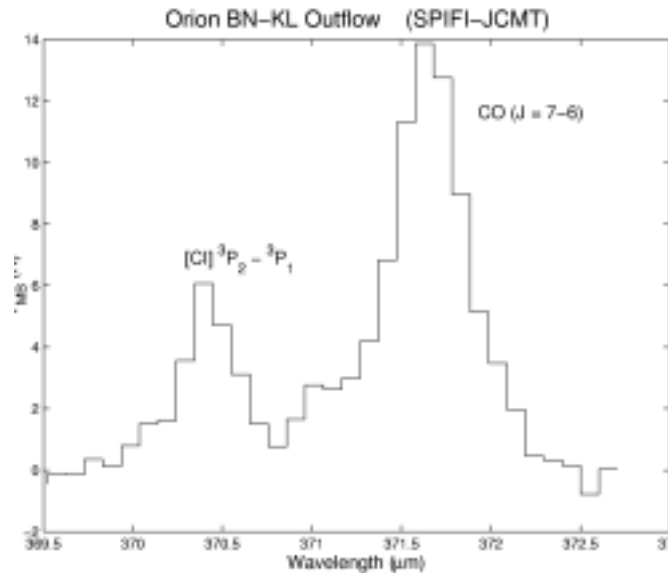
First light with SPIFI was on the JCMT in April, 1999. Operation of the instrument and collection of the data was the result of much hard work. Personnel involved included *Gordon Stacey, Matt Bradford, Thomas Nikola, Mark Swain and Chuck Henderson (Cornell), Jim Jackson and Alberto Bolatto (Boston), Jackie Davidson and Maureen Savage (NASA/Ames), Christine Allen and Tony Stark (Smithsonian), Sarah Unger, Peter Hargrave and Peter Ade (QMW) and Frank Israel (Leiden)*. The team focussed on mapping the CO( $J=7-6$ ) rotational line in the Galactic Centre and external galaxies. Despite rather mediocre weather, the entire circumnuclear ring (200 spectra) was mapped at 7 arcsecond spatial, and 67  $\text{km s}^{-1}$  velocity resolution (Figures 9 and 10). The inner regions of M82 and NGC 253 were also mapped in CO( $J=7-6$ ) line emission (Figure 11) — possibly the first detections of this transition from external galaxies.

In its current configuration, SPIFI can access any line in the 350  $\mu\text{m}$  telluric window. In the near future, SPIFI will be upgraded to access the 450  $\mu\text{m}$  window. The primary lines are the  $^3\text{P}_2$  —

$^3P_1$  [C I] 370  $\mu\text{m}$  fine structure line and the CO ( $J=7-6$ ) and ( $J=6-5$ ) rotational transitions. Goals include mapping the Galactic Center, nearby external galaxies, and ultraluminous IRAS galaxies in these lines, and hopefully, detecting emission from redshifted fine-structure lines at cosmologically significant distances (e.g. [C II] 158  $\mu\text{m}$  at  $z > 1.2$ , [O III] 88  $\mu\text{m}$  at  $z > 3$ , and [O I] 63  $\mu\text{m}$  at  $z > 4.5$ ).

The mid- $J$  rotational lines of CO probe the warm dense gas associated with photodissociation regions (PDRs) and molecular shocks. They are important probes, as warm, dense molecular gas is common in Galactic star forming regions, the Galactic Center, and external galaxies. For PDR gas, the CO( $J=6-5$ ) and ( $J=7-6$ )/CO( $J=1-0$ ) line intensity ratios are sensitive indicators of the strength of the far-UV radiation field, and the gas density. The mid- $J$  lines indicate that much ( $>35\%$ ) of the total molecular gas mass is both warm ( $T > 50$  K), and dense ( $n(\text{H}_2) > 10^4 \text{cm}^{-3}$ ) in both Galactic star forming regions and starburst nuclei. Since the warm gas is an important component, its study is critical to understanding the interplay between star formation and the natal molecular clouds on galactic scales.

Neutral carbon is abundant in the ISM, amounting to 10% of CO in our own galaxy and up to 50% in starburst nuclei. The [C I] lines are easily excited, and are therefore important coolants of PDRs, and perhaps cloud interiors as well. In dense clouds, the line ratio is temperature sensitive, while for more diffuse regions, there is a density dependence as well. Both [C I] lines are normally optically thin, thus tracing mass. The [C I] 370.415  $\mu\text{m}$  and CO( $J=7-6$ ) (371.651  $\mu\text{m}$ ) lines are only 1000  $\text{km s}^{-1}$  apart, so they both can be included in a single spectral scan. SPIFI can therefore map in the two lines at once, saving time, and resulting in perfect spatial registration and excellent flux calibration between the maps.

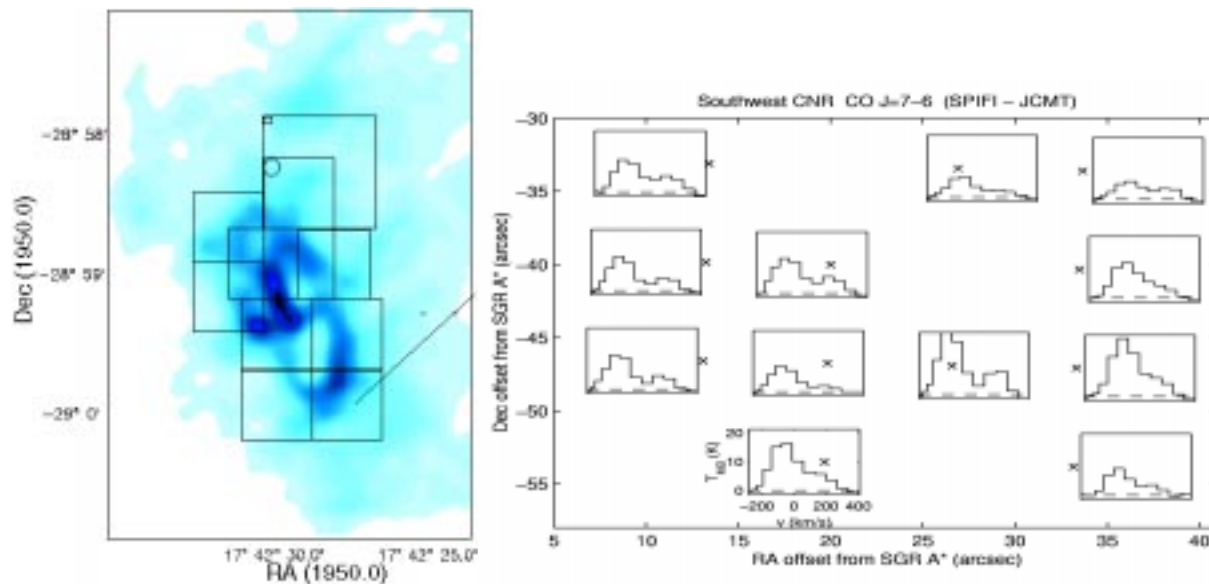


**Figure 8:** [C I] and CO( $J=7-6$ ) spectrum of the BN-KL outflow taken with SPIFI in Sept. 1999. The velocity resolution = 150  $\text{km s}^{-1}$ .

This mode of operation was demonstrated during the September 1999 observing run (see Figure 8). Note that the line separation plus typical extragalactic linewidths ( $\sim 300 \text{km s}^{-1}$ ) and sufficient baseline ( $\pm 100 \text{km s}^{-1}$ ) for a good spectrum, corresponds to  $>4$  GHz at 370  $\mu\text{m}$ , so these experiments are very difficult using heterodyne receivers with typical (1 GHz wide) backends.

The first observing run with SPIFI involved somewhat conservative use of the instrument. For the first half of the run, observations focussed on the CO( $J=7-6$ ) line since the instrument was easier to set up at this wavelength. A velocity resolution of  $70 \text{ km s}^{-1}$  was chosen that could resolve the major velocity features in the Galactic Center, as well as the lines in bright galaxies. This was the lowest velocity resolution obtainable for this run, so that it was not possible to scan far enough to include both the CO( $J=7-6$ ) ( $372 \mu\text{m}$ ) and the [C I]  $371 \mu\text{m}$  lines. During the second run in September 1999, a lower velocity resolution was set up, since the focus here was on extragalactic science. Unfortunately, the weather was quite poor during this run so that very few data were obtained. A small map of M82 in CO( $J=7-6$ ) was possible together with a weak detection of the [C I] line. In addition, a few spectra obtained of Orion containing both the CO( $J=7-6$ ) and [C I] lines demonstrate the large bandwidth.

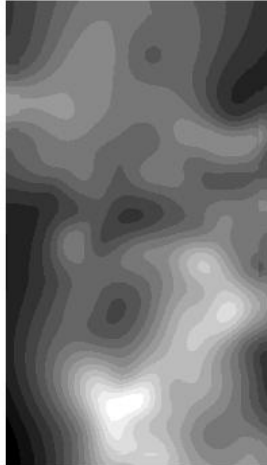
The Galactic Centre Circumnuclear Ring (CNR) is an inclined ring of cloudlets that orbits the dynamical center of the Galaxy, Sgr A\*, at a radius around 1.5 pc. The observed far-IR emission arises from warm dust in photodissociation regions (PDRs). Prominent in these images are the complete inner edge of the CNR, and each of the mini-spiral features (the northern arm, eastern arm/bar, and western arc). These images trace the deposition of far-UV flux (energetics), trace the morphology, and give hints of clumpy structures. However, spectral lines are required for kinematics, and are much better tracers of clumps. Therefore the plan is to map the entire CNR in the [C I] and CO( $J=7-6$ ) lines with SPIFI on the JCMT. These maps will have spatial resolution comparable to far-IR images, so that many of the same features are to be expected, but *velocity resolved*.



**Figure 9:** (left) SPIFI/JCMT footprints ( $4 \times 4$  array) superposed on a  $37.7 \mu\text{m}$  image. Shown is the  $7''$  circular beam, and the  $48'' \times 48''$  footprint of the  $16 \times 16$  pixel SPUD array, together with a  $3'' \times 3''$  pixel. (right) CO( $J=7-6$ ) first light spectrum of the Western Arc. These 12 spectra were obtained simultaneously in an integration time of 12 minutes. Pixels were separated by 7 arcseconds; velocity resolution was  $67 \text{ km s}^{-1}$ , and the telluric transmission to the source was  $\sim 7\%$ .

This project was begun on the first (April 1999) run with a partially filled ( $12 \times 25$  pixel) array, focussing on the CO( $J=7-6$ ) line. Despite rather mediocre weather, the inner  $1'$  by  $2'$  regions were mapped ( $> 200$  spectra!, Figure 9 and 10) in the CO( $J=7-6$ ) line at  $R \sim 4500$  ( $\Delta v \sim 67 \text{ km s}^{-1}$ ). The spectra cover a velocity range of  $V_{\text{LSR}} - 200$  to  $+ 400 \text{ km s}^{-1}$ . This is the first large-scale mapping of the CNR in the CO( $J=7-6$ ) line. The circumnuclear ring and streamer velocities are quite evident in the spectra and in map. The high- $J$  CO line traces the excitation of the ring,

delineating clumps, shocks from clump-clump collisions, and shocks formed where streamers entering the central cavity collide with the ring.



**Figure 10:** SPIFI CO( $J=7-6$ ) contour map of the Galactic Center circumnuclear ring.

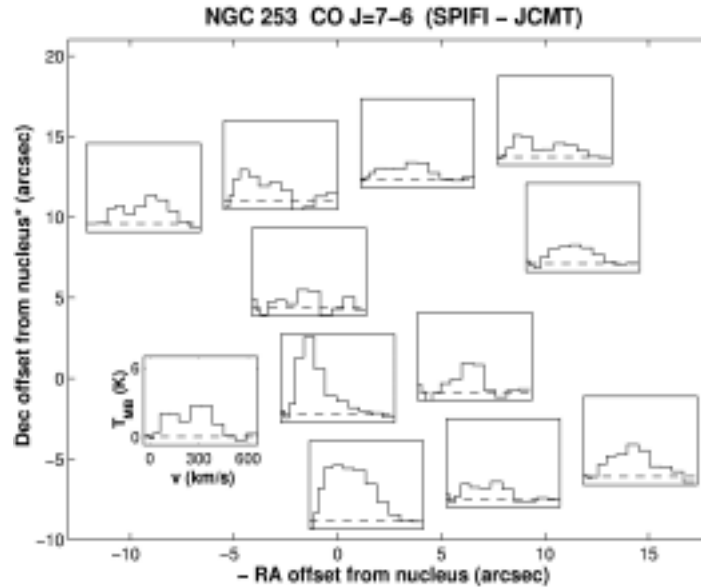
This project will be continued in the May 2000 observing run, when the velocity resolution will be lowered, so that the entire ring can be mapped in both the CO ( $J=7-6$ ) and [C I] 370  $\mu\text{m}$  lines simultaneously. The [C I] line will deliver a complete rotation curve for the ring unfettered by foreground absorptions. This will give, for the first time, good measurements of the overall ring dimensions and mass, and when combined with the  $^3\text{P}_1 - ^3\text{P}_0$  609  $\mu\text{m}$  [C I] maps in the literature, yield cloud temperature, and mass. The CO( $J=7-6$ ) line is sensitive to density enhancements, the local UV radiation fields, and shocks. Enhanced CO( $J=7-6$ )/[C I] line ratios are to be expected from the shocks of clump-clump collisions in the ring, or where the gas from the northern arm crosses the CNR. Morphological and kinematic information from both lines may link the streamers that cross the ring to the infalling gas. The imaging array yields perfect registration and relative calibration between pixels and spectral lines in a map, greatly facilitating the analysis.

NGC 253 is the best example of a nearby ( $D \sim 2.5$  Mpc) spiral galaxy with a starburst nucleus. It is very dusty and highly inclined ( $i \sim 78^\circ$ ). The inner 500 pc contain a massive molecular bar which hosts much of the starburst activity. The far-infrared luminosity of the starburst region is  $\sim 1.6 \times 10^{10} L_\odot$  so that the average far-UV interstellar radiation field is very high, heating and disrupting the ambient molecular clouds.

During one shift in April, fairly good transmission (10% or better towards the source) allowed about half an hour on NGC 253 before the sun began to influence the pointing. However, in this time, a clear detection of the CO( $J=7-6$ ) emission was present in all 12 of the pixels in the array (Figure 11). The main beam brightness temperature was typically  $\sim 3$  K.

Comparing these CO( $J=7-6$ ) map with low- $J$  maps from the literature characterizes the physical conditions of the molecular ISM. The CO( $J=7-6$ ) line, when compared with lower  $J$  CO transitions in an LVG model constrain both the gas temperature and pressure. From measured values at the nucleus, a gas temperature  $\sim 120$  K, and a gas density  $\sim 4 \times 10^4 \text{ cm}^{-3}$  can be derived. By itself, the CO( $J=7-6$ )/CO( $J=1-0$ ) line intensity ratio, is a sensitive indicator of the radiation field intensity and gas density. Comparing the CO( $J=7-6$ ) data to the OVRO CO( $J=1-0$ ) line (similar sized beam), the estimate radiation field is  $\sim 3 \times 10^4$  times the local interstellar radiation field. These physical conditions are similar to those obtained from the far-

IR fine-structure lines, but the area filling factor of the CO( $J=7-6$ ) emitting molecular gas is much lower ( $\sim 0.10$ ) than that of the PDR emitting gas ( $\sim 1.4$  - more than one PDR along the line of sight) indicating that the molecular cores of the clouds in NGC 253 are small relative to their PDR envelopes.



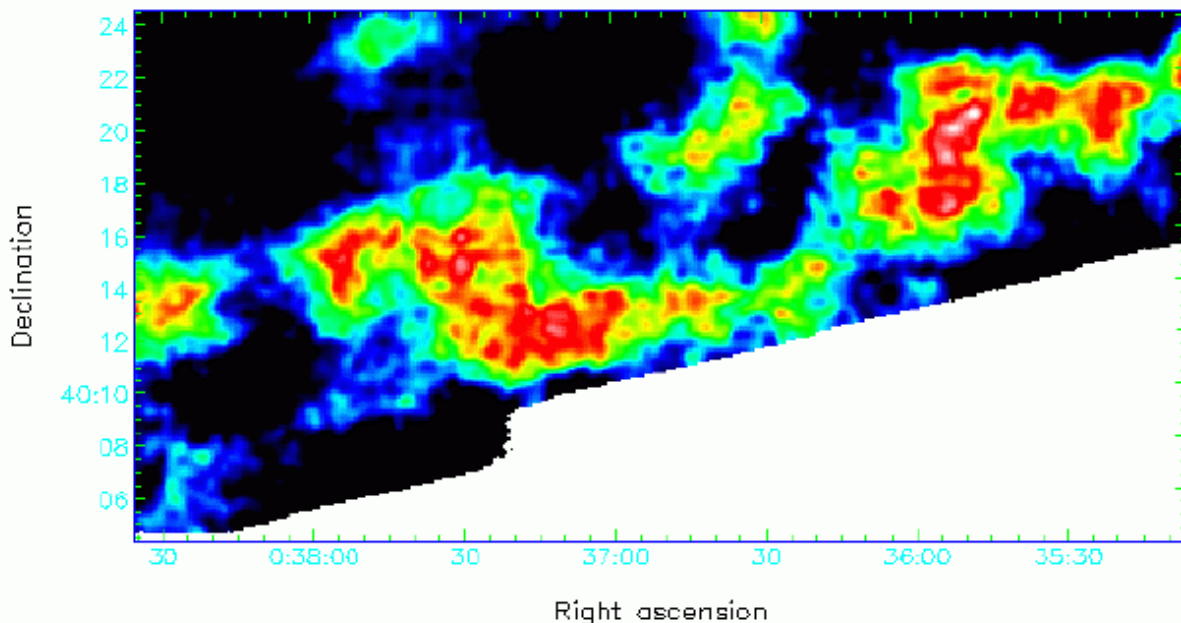
**Figure 11.** First-light spectrum (single footprint of the array) of CO( $J=7-6$ ) line from NGC 253. Velocity resolution is  $\sim 100 \text{ km s}^{-1}$ , total integration time is 25 minutes, and telluric transmission towards the source was 8.5%.

## 2.7 First submillimetre dust mapping of M31

The best global picture of star-formation can be obtained by mapping the interstellar clouds in a nearby spiral galaxy, for comparison to the stellar distribution. However, there is a trade-off between resolution and practicality. For example, at the distance of our nearest neighbour, Andromeda (M31), a beam of 15" corresponds to cloud scales of 50 pc or so, but the galaxy is so large on the sky that it is almost impossible to chop far enough away to be off the emission! *Greaves, Holland and Jenness (JAC), Ryder (AAO) and Alton (Cardiff)* developed a solution to this problem and used this technique to produce the first submillimetre map of dust emission in Andromeda.

Their development of the scan-map technique with SCUBA now allows imaging of very large areas, up to degree scales. Essentially, the telescope is allowed to scan the sky at the maximum rate consistent with obtaining an  $850 \mu\text{m}$  Nyquist-sampled image, and sacrifices the simultaneous  $450 \mu\text{m}$  data, which is undersampled. The limit to this rate is the transputer data buffer, which has a capacity of 52 seconds or about 400 chop-pairs, so by spacing the data points every 7.5 arcseconds; a strip up to 50 arcminutes long can be mapped. As an example, a square area half a degree on a side would fit within this limit, and could be mapped down to noise levels of 100 mJy per beam in a couple of hours.

On the Andromeda Galaxy, the data eventually obtained were 12 maps each  $14 \times 45$  arcminutes in size, from which a mosaic was made covering the whole optical/IR extent of Andromeda, of about  $2.5 \times 0.75$  degrees. (Only on completion did they realise that it would be extremely difficult to handle all 3 million data points!)



**Figure 12:** An 850- $\mu\text{m}$  map of the nearby galaxy, Andromeda.

The reduction is still in the preliminary stage, but a sample of the results is shown in the figure. This is one sub-map from the mosaic, perpendicular to the galaxy's major axis, and shows the end of the '14 kpc ring' at the south-west of M31. Clouds and cloud complexes are visible on all scales from 100 pc up to a few kpc.

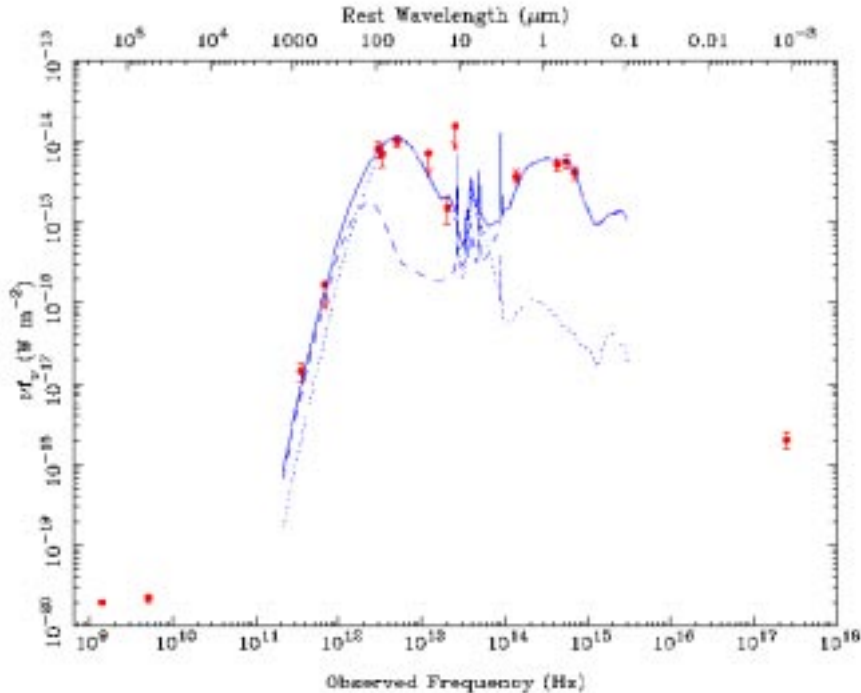
Instead of spiral arms, the most obvious features in the Andromeda mosaic appear to be individual large cloud complexes. These are even more prominent than in a dust map made at 175  $\mu\text{m}$  with ISOPHOT (Haas et al. 1998; *Astron. Astrophys.*, **338**, L33). As noted in that paper, the bulk dust temperature in M31 is lower than for the Milky Way, and so a probable explanation is that only the coldest clouds are visible in the 850- $\mu\text{m}$  map — possibly even a very cold component that has not been found in our own Galaxy.

## 2.8 Submillimetre emission from a ROSAT x-ray galaxy

Deep X-ray surveys have uncovered a population of X-ray emitting objects, which are associated with galaxies with narrow emission lines in their optical spectra (NELGs). These sources are found to have flat X-ray spectra, consistent with the spectral index of the X-ray background (XRB), and hence may be important for the understanding of this radiation. However, the origin of the X-ray emission in these galaxies is still unclear, with the most likely possibilities being either active galactic nuclei obscured by large quantities of gas and dust, or starburst activity, or a combination of the two. This question is the subject of much controversy.

Starburst galaxies and obscured AGN both contain considerable quantities of warm dust and hence will be strong far infra-red/sub-mm sources. Deep SCUBA surveys have found that the majority of sub-mm sources are in the process of vigorous star-formation, but a significant fraction are powered by obscured AGN. Thus the X-ray and far infra-red/sub-mm backgrounds may be intimately linked. A collaboration of X-ray astronomers, *M<sup>c</sup>Hardy and Gunn (Southampton), Newsam (Liverpool John Moores), Almaini (Edinburgh), Shanks (Durham), Georgantopoulos (Athens) and Mason (MSSL)* therefore embarked on a project using SCUBA on the JCMT to search for dust emission from ROSAT X-ray galaxies. Their objective was to

determine whether dust is associated with star-forming regions in the starburst galaxies, or whether dust is responsible for the obscuration of any active nucleus.



**Figure 13:** Spectral energy distribution of R117 from radio to X-ray energies, compared to a model fit of an exponentially decaying 17 Myr burst of star-formation, with an e-folding time of 20 Myrs (dotted line). The optical light (dashed line), contributes about half of the sub-mm flux.

The galaxy R117 taken from the UK Deep ROSAT survey catalogue was detected with SCUBA at 850  $\mu\text{m}$  with a flux of  $4 \pm 1$  mJy. At 450  $\mu\text{m}$ , a  $3 \sigma$  upper limit of  $\leq 25$  mJy was obtained. This galaxy shows narrow emission lines in its optical spectrum, but the optical emission line ratios used as diagnostics for the X-ray emission mechanism (AGN versus starburst) give ambiguous results. A spectral energy distribution has been compiled from multiwavelength imaging and photometry for this galaxy, and is shown in Figure 13. The data are well fitted by a model of an exponentially decaying 17 Myr burst of star-formation, with an e-folding time of 20 Myrs, plus a component due to an older stellar population. The galaxy has extended emission at both radio and mid infra-red (15  $\mu\text{m}$ ) wavelengths.

Thus R117 certainly contains a strong starburst and its far infra-red/X-ray flux ratio agrees very well with previous observations of starburst galaxies. We have been unable to detect any signs of nuclear activity (there are no broad lines in polarised flux) and so conclude that both the X-ray flux and the heating mechanism for the dust in the ROSAT galaxy R117 are due to starburst activity alone. A full discussion will be presented in Gunn et al. (MNRAS, in preparation).

## 2.9 The far-infrared background with SCUBA

The combination of SCUBA measurements with observations at other wavelengths can be particularly powerful. This is especially true of attempts to understand the nature of the various populations of SCUBA-bright galaxies. One tactic is to search for galaxies which are already characterised at shorter wavelengths.

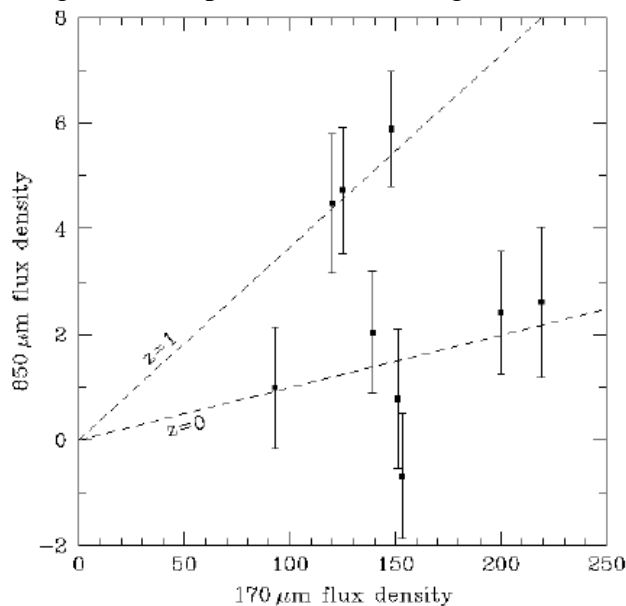
The FIRBACK (Far InfraRed BACKground) survey represents the deepest extensive 170- $\mu\text{m}$  images obtained by the ISO satellite. The sources detected comprise about 10% of the cosmic far-IR background seen by the COBE satellite, and, importantly, were observed at a wavelength near the peak of this background. Detailed follow-up of these sources should help pin down the redshifts, Hubble types, and other properties of the galaxies, which constitute at least the brightest part of this background.

Deep SCUBA observations have already resolved most of the submillimetre background at 850  $\mu\text{m}$ . But it is important to realize that the energy density at these wavelengths is a small fraction of the total far-IR background, which peaks near 200  $\mu\text{m}$ . The strong variation of  $S_{850}/S_{170}$  with redshift makes SCUBA ideal for going after the higher redshift fraction of the FIRBACK sources.

Together with collaborators from the FIRBACK team, *Scott, Borys, Chapman, Halpern and Sajina (UBC)* have been using SCUBA to search for submillimetre emission from a sample of 170- $\mu\text{m}$  sources for which they also have accurate radio positions. A successful run in March 1999 targeted 10 FIRBACK galaxies using the SCUBA photometry mode.

Preliminary results are shown in Figure 14. The vertical error bars represent the 850- $\mu\text{m}$  uncertainties. At present the ISOPHOT 170- $\mu\text{m}$  fluxes are dominated by systematics rather than noise (and hence are more multiplicative than additive) and so have been omitted from the plot. There are several things to learn from this figure. First, none of these sources is very bright! Then there are few negative fluxes, indicating that overall the sample is well detected. Thirdly, the galaxies would appear to split into two groups, with the higher  $S_{850}$  objects probably being at higher redshift.

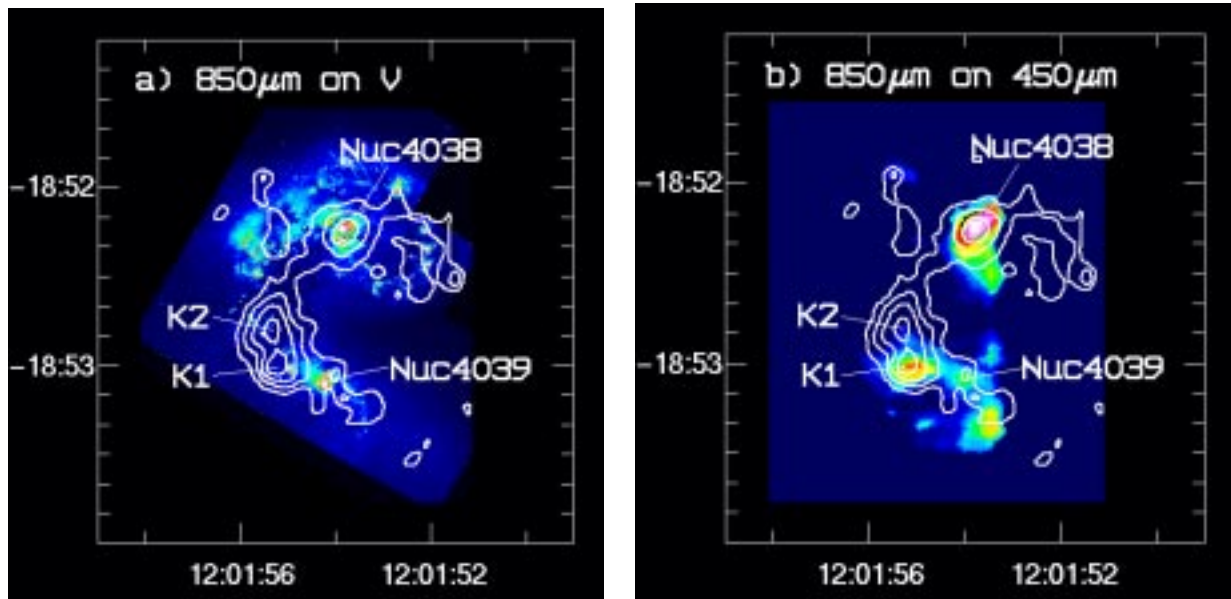
Statistically this sample was also detected at 450  $\mu\text{m}$ , although no individual detection is very convincing. Improved 450- $\mu\text{m}$  data would help constrain dust models for these objects. SCUBA measurements for more of this sample, together with optical, infrared and radio observations should help to pin down the galaxies responsible for the brightest 10% of the far-IR background.



**Figure 14:** The 850- $\mu\text{m}$  versus 170- $\mu\text{m}$  flux densities for the sample observed so far. The dashed lines are for  $z = 0$  and  $z = 1$  models of dusty galaxies (explicitly assuming emissivity with  $\beta = 1.5$  for  $T_{\text{dust}} = 40\text{K}$ ).

## 2.10 Cold dust in colliding galaxies

*Haas and Klaas (Heidelberg) and Coulson (JAC)* have used SCUBA to resolve the nuclei of the Antenna Galaxy. This object is a pair of colliding galaxies, NGC 4038/39, with two prominent regions in the overlap area of the galaxy disks. The SCUBA 450  $\mu\text{m}$  and 850  $\mu\text{m}$  maps coincide excellently with bright emission seen on the 15- $\mu\text{m}$  and 6 cm CO maps. ISOPHOT 60 and 100  $\mu\text{m}$  maps reveal that the overlap area, and the NGC 4038 nucleus are also responsible for the bulk of the far-infrared emission. In addition, to the prominent emission from dust at temperatures of about 30 K, typical for active starburst galaxies, cold dust at temperatures below 20 K is found, typical for quiescent galaxies and dense cloud complexes.



*Figure 15: Left panel: the 850  $\mu\text{m}$  SCUBA map superposed on a visual image of the pair of galaxies; Right panel: the 850  $\mu\text{m}$  SCUBA map superposed on the 450  $\mu\text{m}$  SCUBA map.*

Thus, these observations suggest a common phenomenon for merging galaxies: besides the warm dust heated by active starbursts they possess simultaneously dense concentrations of cold dust which are presumably in a pre-starburst phase. The dust mass in the two overlap region knots is about  $10^7$  solar masses which comprises a considerable fraction (10-30%) of the typical dust content of a whole spiral galaxy. Such a high concentration could be explained by an initial inelastic collision of clouds, which lose their angular momentum and serve as concentrating kernels into which other clouds rotating in the disks are running. The two knots, however, seem to comprise independent kernels, since they are too far separated to be mutually triggered.

### 3. Operations Report

#### 3.1 Weather & Usage Statistics

This has been a horrendous year for high-frequency observing projects. Although the poor weather contributed greatly to the loss of quality observing time, frequent instrumental problems (led by heterodyne cryogenic hold-time problems, and SCUBA impromptu warm-ups) were also a significant contributor to the downtime.

The table below summarizes the weather and usage statistics for the 12-month period from February 1, 1999 to January 31, 2000 (PATT Semesters 99A and 99B). Consult Appendix C for a more detailed treatment. The 'Time Observable' is defined as the total time available for observations (i.e. any planned engineering downtime removed) minus the 'Weather Loss'. The 'Clear Time Lost to Faults' is then defined as the total time lost to faults (from primary or fallback observations) divided by the 'Time Observable'.

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Time Observable	80%	90%	82%	82%	78%	86%	79%	84%	90%	83%
Weather Loss	20%	10%	18%	18%	22%	14%	21%	16%	10%	17%
Clear Time Lost to Faults	6.4%	5.9%	6.5%	3.4%	4.8%	4.6%	4.9%	8.5%	5.0%	12.5%

Prior to the advent of flexible scheduling, 1998, 'Weather Loss' only referred to time lost from primary projects. Flexible scheduling now means that 'Weather Loss' refers only to time lost from fallback projects. Primary projects remain on the observing queue throughout the semester. Using Observer Report data for semesters 99A and 99B, 63% of the primary allocation time was observed (the percentages by country being: UK:CN:NL:Int:UH = 57%:68%:62%:93%:71%). In addition the total time lost to faults has changed slightly to be a function of the time lost to primary and to fallback programmes. Although these changes do not seem to have made significant modifications to the statistics they have resulted in considerably more of the highly important, high-frequency projects being completed than would have been had flexible scheduling not been in operation.

#### 3.2 Antenna, Carousel, Pointing Status

##### *Antenna central bearing*

The central bearing was replaced very successfully on schedule in May. The 22 pitch revolution glitches in the telescope pointing are now completely absent as expected. Live web-cam feeds proved highly successful in informing users and support staff of progress.

The failed bearing has been shipped to the manufacturer for expert analysis. Initial inspection confirmed the hypothesis of a damaged race. Detailed tests are being performed to isolate the cause of the failure and review any implications for future operations.

The empirical correction to the pointing and tracking software has now been disabled since pointing, tracking, and inclinometry tests subsequent to the repair indicate that the effect has now been completely removed.

### ***Antenna balance***

An azimuth spiking pointing problem became clearly evident in the early part of the year. Briefly, the pointing was found to vary by up to 10 arcseconds at particular azimuths but not in a predictable way. It was discovered this variation was due to an interaction between the lightly loaded front wheels of the antenna, the plinth thermal conditions, and the azimuth track profile. This feature was fully eliminated during the central bearing engineering period by adding three tons of ballast to the front of the antenna.

### ***Carousel drives***

Severe problems with the carousel drives were experienced in June resulting in several nights of lost observing time. In early July, an engineering recovery team succeeded in returning the carousel to operation using two of the three drive motor systems. In the meantime, a consultant engineer from the motor manufacturers was immediately flown out and confirmed fears that the system was indeed obsolete and had service parts that were no longer available. He further pointed that the system was obsolete when purchased and that the JCMT had almost 50% of the total production of these motors.

A modern replacement system was specified and ordered in parallel with the drive repair effort. The new system is based upon off-the-shelf DC digital servo-motor technology and provides vastly improved maintenance and support diagnostics. It will be capable of driving the carousel at the original design specifications with a slew rate of  $1.5 \text{ degree s}^{-1}$  and an acceleration of  $0.25 \text{ degree s}^{-2}$ .

The design of the new system was completed and all components delivered by mid August. The new drive motors and control electronics can be installed on short notice in the event of sudden deterioration in the old drives. The replacement system is currently scheduled to be installed during two weeks of heavy engineering early in March 2000.

The new drive system will initially be commissioned at the current slew rate of  $0.6 \text{ degree s}^{-1}$ . Once it has proven reliable at this speed the slew rate will be increased in small increments. It is anticipated that structural and control difficulties will have to be addressed before a speed greater than  $1.0 \text{ degree s}^{-1}$  can be achieved. A risk assessment is planned before the carousel is permanently operated at higher speed. Chief among the safety concerns is the stopping distance of the carousel in an emergency.

### ***Summary pointing accuracy***

The burnout of a carousel motor in July has restricted the frequency of inclinometry data acquisition to once per month or less, but inclinometry data have been very repeatable in this period. Nightly pointing data come mainly from SCUBA (55% of 2000 measures made in this period), with RxA3 generating 21%, RxB3 17% and RxW 6%. Pointing tests with the heterodyne instrumentation are significantly more difficult to perform due to a lack of bright point sources. General pointing performance is still well represented by *rms* errors in each coordinate of (1.5",1.5").

## **3.3 Surface**

Minor adjustments were made in May and July to compensate for seasonal temperature changes. In both cases, the surface was set to a holographically measured accuracy of 13-16  $\mu\text{m}$ , implying

a total accuracy of 22-25  $\mu\text{m}$  when all other errors are also included. The panel adjuster system continued to perform very well during this period, but the current RxH2 holography system experienced many hardware failures and took considerable time and effort to keep it working during the few occasions where it was possible to schedule measurements.

### ***Surface measurement — RxH2 and RxH3***

The new holography system (RxH3) passed its delivery review in late September. The hardware was delivered to the JAC in mid October and installed at the summit during December. The old holography system will remain in service as an aid to initial commissioning of the new system. In order to facilitate parallel operation of the systems, both sources have been mounted inside UKIRT rather than one inside and one on the roof of the dome extension as previously planned. This allows them both to be maintained and operated safely and provides shielding from the potentially harsh outside winter weather.

### ***Surface upgrades — Active surface control system***

Testing of the pre-production boards for the new adjuster electronics has been completed. Several design flaws were identified during this process. These have been eliminated through modifications to the boards which have been proven through extensive further testing. Hence, the decision to delay production of the majority of the hardware to allow for this testing proved well justified. The final adjuster electronics hardware was delivered in late November. Verification testing of the final hardware is ongoing.

The new adjuster electronics will be installed on the summit as soon as practicable subsequent to successful completion of the verification tests. It is anticipated this will occur during January, 2000. These tests will allow the new electronics to be used to adjust the surface immediately upon installation. This can be done with confidence, as the testing will verify the electronics respond to commands exactly as does the system being removed. This procedure eliminates the extremely time consuming task of verifying the operation of each adjuster on the telescope.

Before the new electronics can be safely used to actively adjust the surface for temperature variations, the proper functioning of the limit switches of each adjuster must be verified. These limits along with appropriate software will provide an absolute reference for each adjuster allowing the surface to be quickly recovered in case of faults during commissioning of the active control system.

Testing of the limit switches in a reasonable period of time requires the speed of the new holography system. The testing must still proceed exceedingly cautiously in order to protect the integrity of the surface. Procedures that minimize the checkout time and maximize the integrity of the surface are currently being developed. It is currently estimated that initial commissioning of the active surface control system will commence in mid-2000.

### ***Surface problem***

A very serious glitch occurred in September, when a live test of the new adjuster control system created havoc over one twelfth of the surface area (sector 11). Two subsequent unapproved full-dish adjustments made during the same evening failed to bring the surface back to an acceptable shape. It was determined that the current software was unable to converge on a solution when such a large percentage of the surface was in gross error. Even after reversing these adjustments and manually adjusting most of the run-away panels with a ruler and by eye the next day,

subsequent holography measurements continued to fail to converge to a meaningful solution. The surface was eventually restored to a good shape, but the path to restoration was long, painful and expensive in terms of lost observing time.

The difficulty of resetting the surface exposed a number of weaknesses in the knowledge and ability at the JAC and has caused us to take an extremely cautious approach to the testing of the new system prior to full release in automatic mode.

### *Current surface accuracy*

The state of the surface determined towards the end of 1999 is that the overall rms surface error (from large scale and small scale adjuster moves) is 16  $\mu\text{m}$ . Including the other figures from the error budget (gaps between panels, shadowing by the tetrapod legs, etc) gives a more realistic value of about 25  $\mu\text{m}$ .

### **3.4 Receiver Status**

The JCMT offers a suite of common-user instruments for continuum and spectroscopic observations in the submillimetre wavebands. Major instruments include

- SCUBA — Submillimetre bolometer camera
- RxA3 — Single-channel SIS mixer receiver for 215-275 GHz
- RxB3 — Dual-channel, single-sideband SIS mixer receiver for 315-370 GHz
- RxW — Dual-channel, double-sideband SIS mixer receiver for both 450-505 GHz and 620-680 GHz
- DAS — Digital Auto-correlation Spectrometer; 2048 channel hybrid spectrometer

In addition, the JCMT operates several ancillary observing instruments that include

- SCUBA polarimeter — Released for single-pixel and for array mode towards the end of 1998
- Heterodyne polarimeter — Rotating waveplate polarimeter for RxA3 or RxB3, operated as a shared-risk instrument
- Phase monitor — Phase-monitoring satellite interferometer system operated co-operatively with the Smithsonian Millimeter Array as an observing aid.
- RxH2 — Phase retrieval holography system for surface panel measurements

Visiting instruments at the JCMT during 1999 were

- SPIFI — South Pole Imaging Fabry-Perot Interferometer (Dr. Gordon Stacey, Cornell)
- FTS — Fourier Transform Spectrometer (Dr. David Naylor, Lethbridge)

These instruments, and their performance, are described in more detail below.

### **SCUBA**

SCUBA is a multi-wavelength bolometer camera and photometer. It has 37 pixels in the long-wavelength array and 91 pixels in the short-wavelength array and the two arrays can be used simultaneously. In addition, SCUBA has separate photometric pixels at 2 mm, 1.3 mm, and 1.1 mm wavelength. SCUBA can be used in a variety of observing modes including jiggle mapping

and scan mapping. It was delivered to the JCMT in 1996 and has been operating in production mode since the spring of 1997.

In terms of observing modes, work continues on the development of a scan-map mode, particularly in terms of optimization of chop throws and scan angles. On-the-fly sky dipping is essentially ready, but has not yet been implemented due to other pressures. A new Observation Reduction, Acquisition and Control (ORAC) system has been extensively tested at UKIRT and was imported to the JCMT. The data reduction software, called ORACdr, has continued to develop and has received much positive praise from staff scientists and observers alike. Utility programs (e.g. OBSLOG, SCUNOISE, SCUSKY) have also matured and are routinely used. A Canadian co-op student (Ed Chapin) working at the UKATC during the summer made substantial progress with encouraging results in applying the PIXON deconvolution algorithm to SCUBA data.

Completion of the Phase I upgrade programme took place during July 1999. In summary, this included:

- **new ribbon cables** have been a success in terms of reducing the total number of noisy pixels from ~13% to <5%. The vibration sensitivity of almost all pixels has also been reduced by at least a factor of 2 with the introduction of these new cables.
- two additional **wide-band filters** have been installed in the drum to take advantage of dry weather conditions. These have not yet been fully characterised due to poor weather.
- **new blocking filters** have been installed on both arrays, and have improved the overall transmission of the instrument at all wavelengths. The data are still being analyzed, but significant improvements in per-pixel sensitivity at 450  $\mu\text{m}$  (~50%) and 850  $\mu\text{m}$  (~15%) have been reported.
- a **photon trap** was introduced to prevent possible stray light coming down the dilution fridge insert (thereby giving a broadband excess power loading on the arrays). This appears to have reduced the base temperature by about 5 mK (giving better intrinsic sensitivity), although the new ribbon cables could also have contributed to this (via less heat conduction).
- **cavity modifications** for the photometric pixels do not appear to have improved the performance of the 2 mm pixel as expected, and are currently being investigated.
- the **filter drum** was serviced during the downtime period, with a faulty micro-switch replaced. This was found to be successful shortly after the maintenance period although the filter drum started sticking shortly thereafter. From November onwards the drum has been fixed at the 850/450- $\mu\text{m}$  position and will not be rotated until further investigations can be made in the early part of 2000.

Unfortunately, the upgrade programme had to be split into two periods because of the late delivery of the wide-band and blocking filters. This caused an extra 3-week downtime of the instrument during October. This extra time was also used to correct some problems with the new cables. Another (unsuccessful) attempt was also made to fix the 1.1 mm pixel during this time.

The Phase II upgrade programme is less well defined. Measurements on the SCUBA mirrors revealed an excellent surface accuracy (2  $\mu\text{m}$  rms) and so it is unlikely that they need to be replaced. It is likely that the poor transmission of the blocking filters is (partly) responsible for

the poor system transmission. The cryostat window is also likely to be very lossy at short wavelengths and a new design is being studied.

### ***SCUBA polarimeter (Spol)***

The polarimeter has been used very successfully for 11 projects since April 1999, including the first imaging polarimetry at 750/350  $\mu\text{m}$ . Data reduction has been very greatly improved, to the extent that it is fully automated in the 'pipeline' software (in imaging mode), and this is in turn encouraging more polarimetry users.

The individual instrumental polarization measurements at 850  $\mu\text{m}$  were updated in July, so that all now have errors  $\leq 0.4\%$  (mean of about 0.25%). Tests were done on reducing the large 450  $\mu\text{m}$  instrumental polarisation (which is due to a match with the weave spacing of the membrane), by installing an orthogonal membrane section inside the receiver cabin, over the elevation bearing. The results were very promising, with at least 75% of the instrumental polarisation cancelled, down to a level below 1% (comparable to all the other wavelengths). No changes have been made to the instrument hardware, but some further revision is planned for the polarimeter mounting system, which is somewhat awkward to access.

### ***RxA3***

When RxB3 was commissioned on the JCMT, its predecessor, RxB3i was converted by HIA for use in the 230 GHz band (A-Band). The receiver is now known as RxA3.

RxA3 has a tuner-less mixer that covers the 215-275 GHz frequency band. The SIS device was designed by NRAO, fabricated at the University of Virginia, and mounted in a block manufactured by HIA. The receiver also has a tuner-less tripler in the local oscillator chain. Consequently, the receiver is very quick to configure and easy to use. The cryostat has been fitted with an ion pump that improves its hold time. The receiver was built with ease of use and reliability in mind since the A-Band can be used as a fallback in mediocre weather on any given night. It was delivered in late November, and commissioned during December 1998 and the early part of 1999.

In May the instrument showed a dramatic decrease in cryogenic hold-time from about 10 days down to 2.5 days. An initial inspection showed no obvious causes. In response to pressure on staff astronomers to support the administration of the fallback programmes in poor weather, the JCMT Board approved the temporary removal of RxA3 from service. The receiver was removed from the cabin on 20 July for repairs. Dr. Stephane Claude (HIA) worked with local staff in stripping down the cryostat in late July. Two spacers between the inner and outer radiation screens were found loose and a screw from one of them was lodged between the outer screen and dewar wall. After the repair, the hold time improved to around 4.5 days, but was still significantly reduced.

RxA3 was replaced in the cabin at the end of September in order to be available for PATT-allocated highly rated programs, but was removed afterwards because it was a significant drain on resources to keep the instrument constantly available as a fallback. The next plan was to use the outer cryostat from the retired receiver RxC2 in place of the original RxA3 (B2i) cryostat; HIA Victoria assisted with this work in November. The RxC2 dewar has a demonstrated hold time in excess of 14 days, and thus the refurbished RxA3 should provide a dependable longer-wavelength heterodyne facility for the JCMT, which was the reason for moving from the old RxA2 cryostat to RxB2i in the first place. But in early December attempts to remove an ice

blockage from the liquid-helium fill tube resulted in damage to the tube, creating a further vacuum leak in the cryostat. The instrument will need welding repairs to the cryostat before it can be returned to service, hopefully, in the middle of the year 2000.

### ***RxB3***

RxB3 is a dual-polarization, single-sideband heterodyne receiver covering the 315-370 GHz frequency band. It can reach a given noise level a factor of 4-8 times faster than its predecessor, RxB3i. The receiver tunes fully automatically under computer control, which saves time for setup and reconfiguration. Because it can be tuned single-sideband, not only is the noise improved but the calibration is also more stable and reproducible.

During spring 1999 the instrument showed significantly increased tuning problems with a consequent impact on observing time, user aggravation, and staff maintenance effort. It was removed for a thorough overhaul of all the electronic systems and a replacement of one of the mixers with a new tunerless version by HIA staff in May. Work on the tuning difficulties continued through early July, progress being severely impacted by staffing problems. During this time software changes to the microcomputer code overcame one of the major causes of faults, in the double-beam interferometer control.

RxB3 was reinstalled in the cabin on 7 July, where the new mixer showed excellent performance from the first observation the following day. Some tuning faults continued however, and further efforts were able to effect a decrease in these by improved tuning procedures. The failure of the second tunerless mixer has resulted in the original mixer being re-inserted and RxB3 was re-installed on the telescope on 11 October.

### ***RxW***

RxW, delivered in June 1998, covers two frequency bands, 430-510 GHz (C-Band) and 630-710 GHz (D-Band) with dual-polarization, single-sideband receivers. It represents a significant improvement in sensitivity at C-Band relative to the older receiver, RxC2. The D-Band provides the first capability in this band by a common-user instrument at the JCMT although the performance is below the specifications. Replacement of the D-band mixers was scheduled for the summer of 1999 but this has now been delayed until February 2000.

RxW has not been extensively used during 1999, but when called upon has generally performed quite well, especially at C-band. There have been a few tuning problems reported, but one persistent difficulty has been the tendency for the compressor to trip out and the receiver to warm up. Due to the limited availability of nighttime shifts for testing, the receiver has still yet to fully complete formal commissioning. This is certainly true at D-band, where one channel has been unavailable due to the HEMT amplifier being shorted inside the cryostat, and the late delivery of the final set of mixers. The latter will provide considerably better sensitivity at D-band and should spark more interest amongst the community in observing at these frequencies. These new mixers are currently anticipated to arrive in February 2000.

### ***DAS***

The DAS (Digital Auto-correlation Spectrometer) is a general-purpose spectrometer used with all JCMT heterodyne receivers. It is a hybrid spectrometer, meaning that its total bandwidth is made up of several, contiguous analogue base bands that are auto-correlated independently and joined to produce the final bandpass. The DAS has 2048 total spectral channels distributed over

16 hybrid sub-bands. The maximum bandwidth is 1840 MHz in one IF channel or 920 MHz in two channels. The minimum channel spacing is 78 kHz. The DAS is a very stable instrument and produces spectra of very high quality. It provided excellent service throughout 1999.

### ***SPIFI***

The South Pole Imaging Fabry-Perot Interferometer (SPIFI) is an imaging spectrometer available for use on the JCMT in the 350- $\mu\text{m}$  atmospheric window. The PI for the project is Prof. Gordon Stacey of Cornell University. SPIFI employs a 5 x 5 bolometer array, with the detectors arranged in a square grid and separated by 7 arcseconds in the focal plane. The field-of-view of the instrument is about 35 x 35 arcseconds.

The team began assembly in late August. After about a week of standard assembly and warm checkout, the instrument was pumped down. On beginning the cryogen fill, a leak surfaced in the liquid helium neck tube. The instrument was warmed, opened, and the leak was localized with the leak checker. Due to the limited access, the only approach short of a complete disassembly was to attempt to cover the leak with epoxy. This seemed to work as the dewar pumped down perfectly, but unfortunately, the leak opened up again when cold. This time the adiabatic demagnetization refrigerator cryostat was taken apart, and the stainless-steel neck tube was patched properly by soldering on a small piece of copper. This was satisfactory, but unfortunately, a different leak surfaced in the neck as the dewar was cooled a third time. This leak was about an order of magnitude smaller, and would have been tolerable, but for the tiny heat capacity of the refrigeration unit. After trying with some success to eliminate the leak without opening up, the dewar was eventually warmed again and the neck tube replaced. This represented a good deal of effort from the entire SPIFI team, but the result seemed to be a success, and instrument was cold in time to begin a late scheduled observing run in late September.

Scientifically, it was a challenging, yet somewhat successful run. Of the six nights on the telescope, 4 were totally lost due to weather. During the two nights with usable weather, instrumental problems lost some time, but some of the science highlights are described elsewhere in this report.

The entire SPIFI instrument has been shipped back to Cornell for work on the neck tube. The failure of this neck tube can be attributed to the lack of any flexible coupling between the cold portion of the cryostat and the warm vacuum shell. The existing neck will be replaced with one that includes a flexible coupling in the lab at Cornell before the next run in spring of 2000.

### ***FTS***

The Lethbridge FTS is a polarizing Fourier Transform Spectrometer based on the two beam Martin-Puplett design which has been developed by the University of Lethbridge group in Alberta for use at the JCMT. This instrument is ideally suited to observational programs which require a broad spectral coverage at intermediate resolution ( $R \sim 40 \text{ km s}^{-1}$  at 350  $\mu\text{m}$ ). Originally designed for use with UKT14, the compact and efficient FTS is mounted at the right Nasmyth platform, and employs its own dual polarization bolometric detector system. The advantages of the polarizing interferometer include a high and uniform efficiency over a wide wavelength range, access to two input ports and well defined radiation paths within the interferometer, essential in the calibration of resulting spectra. The FTS system is completely standalone.

In December, the FTS run was setup to be flexibly scheduled for 2 shifts out of a run of 5 shifts. Since the weather the previous week had been abysmal, and since only 2 shifts of FTS observing were scheduled, careful planning was required using the latest available weather forecasts for Mauna Kea to optimize the observing. However, the run was essentially completely weathered out with no submillimetre quality nights during the entire period. The FTS and detector system performed flawlessly throughout the 2-week period of preparation and observing and the group fully supported the mode of flexible scheduling that CTAG was implementing. It offered the best chance of scientific return for the FTS programs.

On the final day observing continued through till noon. The group obtained solar spectra at a variety of limb positions in the 450- $\mu\text{m}$  band in an attempt to extend their detection of high- $n$  solar Rydberg transitions of hydrogen. Initial analysis indicates that while the atmosphere was relatively opaque, it was very stable and may yield the first detection of the  $n = 22 - 21$  line.

### **3.5 Software**

The commissioning of the SCUBA imaging polarimeter in the first half of the year has finally allowed the software group to ‘turn the corner’ in that SCUBA no longer dominates the staff effort. This has finally enabled a focus on other projects. Whilst these other projects have not been completed this year, there is a realistic chance a number of them will be completed in the early part of 2000.

#### ***Hardware and operations***

The basic computing hardware has been fairly reliable with the exception of a system board failure of the VAX/VMS file server. This was replaced before the problem became too serious. The software group has also been impacted by the problems with the heterodyne instruments and the carousel. During the maintenance of RxB3, some long-standing problems with the micro-controller software have been able to be identified and fixed. On SCUBA, many causes of the system hangs that had been occurring have also been identified and solved.

#### ***Instrument development***

The major common-user instrument development work has been commissioning the SCUBA polarimeter. The data reduction software was implemented, ably supported by the Starlink upgrades to the software, as an extension to the current SCUBA data reduction software.

In addition, significant software development effort has been committed to two visiting instruments. Extensive software support was available for SPIFI during their successful run in April, and a significant amount of time has been spent implementing the control task for the MPI 800 GHz receiver, which was expected in November, but has now been postponed until April 2000.

#### ***Surface Control System***

This consists of the old panel adjuster, active surface control and holography projects. The software contribution to this consists of a number of roles including project management, software design, and development of the holography data acquisition software. In addition, this project has made good use of a number of University of Victoria co-op students, with Keith Grennan currently assisting with the panel adjuster software.

### ***Telescope Control System (TCS)***

This project is finally getting the focus it requires to bring it to completion. Installation and implementation of the UKIRT servo system in a fairly short timescale cured the recent problems with the servo. This system now controls all major sub-systems and has been tested with both the heterodyne instruments and with SCUBA. It is scheduled to be in regular use in the spring of 2000.

### ***Observatory Control System (OCS)***

Meticulous development and testing of recipes for the new OCS has been ongoing, with Dennis Kelly, at the ATC, making significant improvements to the Telescope Observation Designer and Driver (TODD). A queue manager for feeding Observation Definition Files to the system has also been completed. This OCS is now nearly ready for release on the heterodyne instruments, but work on the project has been lowered in priority in the effort to get the TCS finished. Work to implement the project for SCUBA has been postponed pending the SCUBA-2 conceptual design review. If SCUBA is not to be upgraded the plan is to probably continue with the existing VMS based system.

### ***Observation Management Project***

This project has been slowly ramping up during the year. A successful workshop was held in March in association with the UKIRT ORAC Scheduler PDR. The outcome was the decision to merge the JCMT and UKIRT projects into a single JAC Observation Management Project.

### ***Other projects***

With all these projects still ongoing, it is clear that other work has had to suffer. Commitments for the Real Time Sequencer were unable to be completed, and the implications to the ACSIS project are currently under discussion. Effort to integrate the JCMT into the SMA will not be available over the next 12 months and the impact of this will depend on the progress of the SMA's commissioning schedule. Secondary mirror upgrades that are desired by the ACSIS project will also have to be delayed until effort can be found.

## **3.6 Staffing**

The staffing problem remains difficult throughout the year with a large number of staff changes. The ongoing difficulty of recruitment of a senior electrical/electronic engineer for the JCMT suggested an alternative approach — an internal reorganization. Tim Chuter has taken on responsibility for JAC electrical/electronic engineering and a junior engineer will be recruited. As part of this reorganization, Sydney Arakaki has assumed the role of instrument support for both the JCMT and for UKIRT.

Phil Jewell, Head of JCMT Instrumentation, announced his resignation as from the end of December 1998 to take over as Director of the Green Bank Telescope. Phil has done a tremendous job in his short tenure with us and will be a very hard act to follow. Per Friberg was appointed as the Head of Instrument Development, and the remainder of Phil's duties was split amongst other staff in the instrument group and the finance section.

The announcement of the resignation of the Telescope Manager, Richard Prestage, to move to a senior post with NRAO at Tucson, signalled another major loss for the JCMT. Richard will be

enormously missed due to his detailed knowledge of the telescope, his staff management expertise and his all-round outstanding ability. In his ten years with the JCMT, Richard has played a major role in so many aspects of its development that it would be hard to find areas in which he has not contributed. Wayne Holland was appointed as JCMT Telescope Manager in September and took up the post in November.

A reorganization of science staff resulted in Per Friberg managing the instrument scientists and Wayne the remainder of the group.

New arrivals in the JCMT Science group were Elese Archibald, who arrived in September, as a research fellow working with SCUBA. She is supported by the PPARC research initiative and will also undertake some level of support as well as responsibility for outreach. Also, Robin Philips joined the JCMT in October as a heterodyne instrument support astronomer.

The JCMT Telescope System Specialist team lost two members during the year. Jim Pomeroy, left in early July to take up a position as a geothermal well operator in Utah, where he now lives with his family. Later in the year Kimberly Pisciotta tendered her resignation for early December.

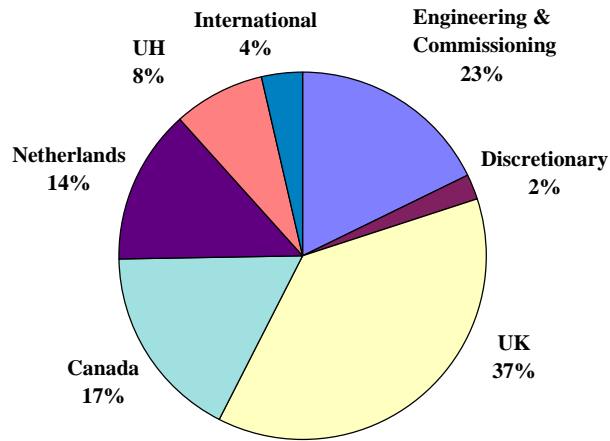
The Administration Section underwent several staff changes of duty through the year with Roxana Myers terminating her employment in August to return to higher education (UH - Manoa) to obtain her Masters degree in Plant Molecular Physiology. Desiree Milar-Okinaka was promoted to the vacant post of Fiscal Administration Assistant. Velvet Gonsalves-Nases was promoted to Accounts Clerk in August (Desi's post). Velvet had been hired in March as the Accounts Receivable/Payable Clerk. In November, Felisa Teramoto was employed to fill this position.

In the Engineering and Technical Services group, the Chief Engineer, Justin Greenhalgh, ended his tour of duty in June and returned to the CLRC, UK to take on a completely different project. Dean Shutt was appointed to this position of Chief Engineer and took up the post in May, allowing some overlap with Justin and managing to avoid holding absolute responsibility for the antenna central bearing replacement.

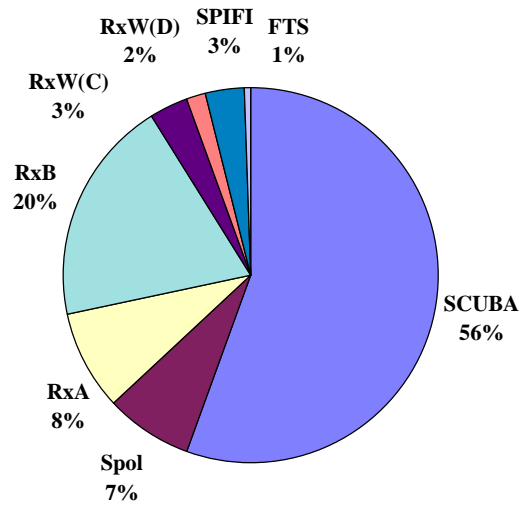
Chase Reed, Electrical Technician, terminated his employment in July to take up a similar position with the Keck Observatory. Brad Gom joined in September as a JCMT Instrument Support Engineer. Eric Kenessey was appointed as a JCMT Electronic/Instrumentation Technician and began at the JAC in February. He left after a few months and Peter Oshiro was hired in September for this post.

The resignation of Richard Prestage left a gap at the top of the JCMT software group. Nick Rees was appointed to fill a new position of Head of JAC Software and Computing Services. This position is responsible for the software on both telescopes and replaces the Head of JCMT Software Group. Mary Fuka has decided to reduce her working hours by 20% from the beginning of October, in preparation for her eventual retirement in May 2000. Russell Kackley, who had been a Student Assistant working with Nick Rees for the summer was successfully recruited in September for a limited term appointment of one year as a Software Engineer.

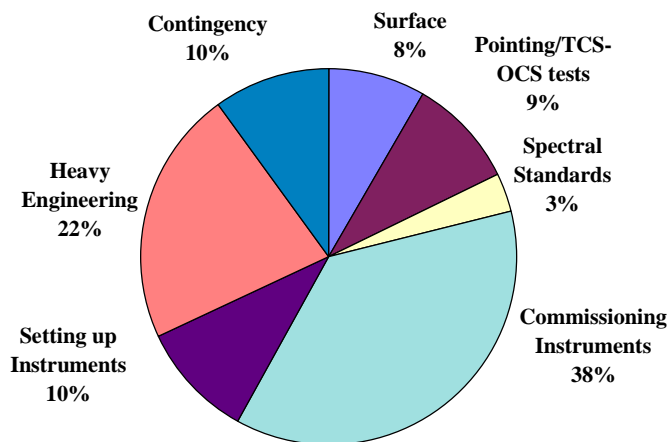
**PATT Allocations**



**Receiver Allocations**



**Use of Engineering & Commissioning Time**



**Figure 16:** Analysis of telescope usage during the two semesters in 1999.

## 4. Instrumentation Programme

During this year, detailed project plans and work packages have been defined for the HARP-B project. Much other work has also been begun on both the HARP-D and SCUBA-2 projects. Unfortunately, the planned mixer upgrade for RxA3 had to be postponed due to other problems with the instrument.

In the second part of the year a very successful completion of the SCUBA phase I upgrade was performed and RxB3 received an upgrade of two new tunerless mixers. The tunerless D-band mixer upgrade for RxW has slipped into February 2000. The source and receiver for the new RxH3 were received and installed, with further commissioning scheduled early in 2000. The Radio Frequency Test & Monitor (RFTM) project has been delayed due to assembly problems.

### 4.1 Instruments under construction or upgrade

#### 4.1.1 *Wide-band mixers (MRAO)*

The wide-band mixer program at MRAO has been very successful and the design developed from the studies is the base for the HARP-B mixer design. Most of the laboratory work has been completed; final testing is waiting for SIS devices tuned to the required frequency. After testing a final report on the complete project will be delivered.

#### 4.1.1 *RxH3 Holography System (MRAO / RAL / JAC)*

RxH3 is the new holography measurement system for the JCMT. It operates at 80 and 160 GHz and measures phase and amplitude. Frequency sweeping is also included to suppress unwanted reflections. The goal is to measure the antenna surface with higher accuracy and speed than before. The specification was a complete surface map in 10 minutes with a repeatability of 5  $\mu\text{m}$ ; in fact it will now achieve this in 15 minutes. Currently a surface map takes 2 hours and is repeatable to 12  $\mu\text{m}$ . Further, phase retrieval and other features, such as using dual frequency operation, are expected to improve the accuracy as well as the repeatability. The two frequencies allow for fast mapping of large-scale features while supporting more accurate measurements of small-scale errors. This system is an integral component of the surface upgrade program.

RxH3 development is led by MRAO, in collaboration with RAL and JAC. MRAO are responsible for the concept, the IF correlation section, phase locks, system integration, data analysis software, and delivery of the final system. RAL was responsible for overall RF design and building/packaging the radio frequency (RF) modules (receiver and source). The JAC provided the basic design layout following the conceptual design by Richard Hills, supplied RF components to RAL on behalf of MRAO, and is supplying the control computer, the data acquisition unit, the control task and the mechanical infrastructure.

The project team successfully resolved the design flaw discovered early in the year. The receiver and source was tested at RAL in February/March with the result that the source output power was found to be too low while the receiver basically did not work at all due to local oscillator (LO) starvation. With an additional Gunn the LO power is now sufficient to drive the mixers in the receiver with good performance. The receiver noise temperatures have been measured at 800-1000 K, well below the specification of 2400 K. Delivery of the receiver and source were made in September. The integration with the data acquisition unit began in late October. Further commissioning will follow during in the first half of 2000.

#### 4.1.2 Water-Vapour Radiometer (MRAO)

The water vapour monitor measures the brightness and profile in three atmospheric windows of the 183 GHz water line. These data can be used to estimate the extra delay in the atmosphere, due to water vapour, for interferometry phase corrections, or to estimate the precipitable water vapour. The latter is useful for opacity estimates. In contrast to the CSO  $\tau$  meter, the water vapour monitor looks in the direction that the telescope is pointed and does not depend on a plane parallel atmosphere model.

The project has moved forward, albeit very slowly. A preliminary version of the reduction software that estimates the precipitable water vapour content above the telescope has been compiled. Work is now ongoing to provide code to convert these numbers to opacities. The JAC software group will supply code for reading the elevation and temperatures from the online system to simplify the testing and commissioning.

#### 4.1.3 Radio frequency test and monitor system

This was approved at the November 1998 Board meeting. Displays of phase lock IF and injected test signals are routine monitoring and testing operations but these tasks have so far been done in a rather *ad hoc* way at the JCMT. The RFTM system is designed to allow routine monitoring and testing by the TSS without installing extra equipment or switching cables. This also helps remote diagnosis of faults by support staff.

Good progress has been made despite delays early in the year caused by supplier problems. All design procurements and manufacturing of parts have now been completed. The remaining tasks are assembly of the micro-strip structures. This is a task that requires skills not currently available at the JAC. It has proven difficult locating a suitable agent for this task, but this is in-hand.

#### 4.1.3 The ACSIS Correlator (HIA/UKATC/JAC)

ACISIS is the backend for the HARP program. The correlator is of a hybrid design and has 32 correlators capable of handling 1 GHz bandwidth. The anti-aliasing filters reduce the bandwidth to around 800 MHz. Thus with overlap the correlator can handle 32 x 800 MHz, 16 x 1.6 GHz or 8 x 3.2 GHz etc. The allowed IF input band is now 3.5 to 8 GHz but discussions about the lower limit as well as the effective bandwidth are ongoing. These specifications are important for the HARP-B project.

ACISIS is a distributed project centred at HIA Penticton, which is performing the project management, system engineering, digital section and data acquisition. Other major work packages are at the UKATC with the project scientist and the real-time analysis software, HIA Victoria with the IF down converter control and infrastructure and at the JAC with the IF down converter RF section and telescope infrastructure.

An internal design review was held in June. The main objective was to review the final design and identify any problems before building and testing individual hardware units or software modules. Units and modules should be ready and tested before the planned Critical Design Review in July 2000. Modifications suggested by JAC staff mainly concerned maintainability. The review and discussions also resolved the outstanding cooling requirements. The ACSIS electronics will be located under the antenna so it is vital for the antenna surface quality that any excess heat is removed. For the ACSIS project the escalating cost of the cooling was of grave

concern. However, the outcome of the review was a project on budget and on time. The resolution to the interface issues from software to cooling was agreed in a list accepted by the JAC and the ACSIS project.

Some areas of concern are the sampler construction and the delay of the JAC supplied Real Time Sequencer (RTS). Towards the end of 1999 the sampler boards were received and testing is imminent.

#### *4.1.4 The HARP-B — 345 GHz Focal Plane Array Receiver (MRAO)*

The HARP-B project was approved by the Board in November 1999. It is a 16 channel 350 GHz SIS focal plane array to be placed on the Nasmyth platform opposite to SCUBA. The project is managed by MRAO with contributions from the UKATC and HIA. Following the November approval the project team worked very hard to produce a Conceptual Design paper. Indeed, a very successful Conceptual Design Review was held in March. The external panel thought the program was very good but challenging. A number of critical areas were pointed out where early design freezes would be essential in order to achieve the deadline. Work progressed towards defining a better project plan and work packages for each laboratory. The revised project plan now has an additional year of work (which also includes a more realistic laboratory testing phase) with delivery to the telescope in June 2003. The current conceptual design would allow other arrays to operate on the Nasmyth by physically sliding them into place.

## **4.2 Long-term Development Plan**

The focus of JCMT development activities is

- Efficiency improvements – by upgrade routes
- A programme of sub-arcsecond astronomy
- Provision of heterodyne focal-plane arrays and associated correlator
- Potential new (innovative and fast track) instruments

### *4.2.1 Mixer upgrades (HIA/SRON)*

#### *4.2.1.1 A-band*

RxA3 was delivered to JCMT in December 1998. The receiver initially worked very well but has a problem with the noise performance in some parts of the pass-band. For LO frequencies between 244 and 262 GHz the noise is higher than expected and this is thought to be due to a problem with the junction substrate. HIA spent considerable effort on supplying a new mixer. The first mixer block was unfortunately lost in transit between Ottawa and Victoria when the transport plane crashed. The block now in use is from RxA2. (RxA2 was shipped back to HIA in early February). Expected commissioning of the new mixer on the telescope has been delayed due to cryogenic hold-time problems with the instrument described elsewhere.

#### *4.2.1.2 B-band*

This project is to provide tunerless mixers for RxB3. One of the two new tunerless mixers was installed in May and has been operating well, providing increased sensitivity and bandwidth. The second mixer was delivered and installed in September but it shorted during cool-down. It was removed and sent back to HIA for testing. Inspection showed that contacting parts had

slipped within the mixer block. The mixer was repaired and thermally cycled several times prior to shipping. It was delivered and installed in early November, and performs well.

#### *4.2.1.3 D-band*

It was known before delivery that the D-band mixers in RxW suffered from high noise temperatures. The main reason is a large degree of cross polarisation in the mixer diagonal horn combination. The unwanted polarisation gets dumped into a cold load but also appears as a loss increasing the noise temperature. An upgrade was agreed whereby SRON would replace the mixers at cost. SRON is making three new mixers equipped with corrugated horns manufactured by RAL. The mixers have been tested with excellent results and will be delivered in February 2000 for commissioning.

#### *4.2.2 SCUBA phase II*

The SCUBA phase II project is to investigate fast-scanning (no nodding). Prior to further phase II work more telescope tests are required, concentrating on modified secondary mirror waveforms to reduce the bolometer susceptibility to vibration (the new ribbon cable may also help in this area). Although not completely discounted, the differential amplifier and vibration isolation studies are no longer being actively pursued as realistic options.

The recently completed SCUBA Phase I work might reduce the sensitivity to microphonics that plagued the original tests. Also, parabolic velocity profiles for the secondary jiggling were tested in November. These softer velocity profiles are expected to further reduce the microphonics.

Measurements on the SCUBA mirrors revealed an excellent surface accuracy (2  $\mu\text{m}$  rms) and so it is highly unlikely that they need to be replaced. It is probable that the poor transmission of the blocking filters were (partly) responsible for the poor system transmission. The cryostat window is also likely to be very lossy at short wavelengths and a new design is being studied.

The major work on this project will likely be undertaken during the year 2000.

#### *4.2.2 SIS junction programme (SRON/RUG)*

The SIS contract with SRON Groningen expired at the end of June 1999. Negotiations about an extension of the contract have been ongoing since the fall. The JCMT is keen on renewing the contract since a change in supplier would be complicated, time consuming and cause disruptions of the HARP-B programme.

The contract has been managed by SRON on the Netherlands side although the group performing the actual SIS device manufacturing is a part of the University of Groningen. A further complication is that the device manufacturing group has moved from Groningen to the Technical University at Delft, which is a positive move since this university has better facilities.

If the Netherlands find staff effort for manufacturing devices for the HARP-D programme this could also include the manpower for the HARP-B devices. As a result, a draft contract has been discussed that involves supplying junctions to MRAO for HARP-B and related work. A similar contract would be implemented for HARP-D devices if approved. The concentration on HARP-B would satisfy JCMT's highest priority.

### *4.2.3 Sub-arcsecond interferometry with the SMA*

The SMA project achieved a major milestone at the end of September when fringes were detected between the two first antennas on Mauna Kea. The data acquisition system, which the project leader took great pleasure in describing, was a chart recorder.

The SMA project has been under severe time pressure to achieve the above milestone. The optical fibers between the JCMT, SMA and CSO were pulled into place in November. No testing has been done since the cable installation. Delivery of the receiver/transmitter units for these fibers is expected in early January 2000. If this, optimistic schedule holds up, phase stability tests and even test observing may be performed during the spring of 2000.

During the spring/summer of 2000, the JAC microwave effort on the ACSIS project will decrease. This will free resources to work on the modifications needed to the phase-locks and IF system for joint SMA operation. In conjunction with the HARP-B project, Berkshire Technologies Inc. has been contracted to supply a 5 GHz HEMT with a 2 GHz bandwidth. These HEMTs will be needed for upgrading the IF system from 4 to 5 GHz for SMA operation. The current plan is to install these during 2001.

### *4.2.4 Innovative new instruments*

#### *4.2.4.1 SCUBA-2*

SCUBA phase III, now called SCUBA-2, is the future provision of what is almost certainly believed to be a new instrument for the facility, utilising new technologies in array design. Although an array upgrade sounds at first attractive, the complexities of SCUBA mean that a new instrument is probably the most pragmatic solution to maintaining a lead over the competition in the most cost effective manner. A close watching brief (through personal visits to labs) is being maintained on the development of new detector technologies, particularly for the FIRST bolometer instrument. Towards the middle of the year significant progress in locating a source of bolometers was made and this project has been ramped up in priority following the successful SCUBA upgrade work in July.

#### *4.2.4.2 HARP-D*

The proposed HARP-D would be a cloned version of the CHAMP instrument used on the CSO to work in D-band. It would be built jointly by SRON and the MPI für Radioastronomie and would be on loan to the JCMT for at least 2.5 years, with a possibility of another year before moving to the ALMA site. It would have 16 elements, with minimum spacing on the sky. It would come with its own auto-correlator and could provide 2 GHz of bandwidth for each detector.

The changes from CHAMP(C) are the signal and local oscillator (LO) optics, the mixers and their corrugated horns, and the LO components such as Gunn oscillator, multipliers and LO distribution system. The LO tuning range covers the 625-720 GHz atmospheric window with an IF bandwidth of at least 2 GHz in the 4-8 GHz range. This corresponds to a velocity width of  $1500 \text{ km s}^{-1}$  for each pixel. To obtain optimum system sensitivity the design includes cold optics (15K) and an optically tuned single-sideband separation. The intention is not to use a beam detrotator as the observing strategy will allow sufficiently short observations so that the rotation corrections can be done in software.

#### *4.2.4.3 Wide-band extragalactic receiver*

This could be an exciting development, making use of the new potentially very wide-band mixer availability and the ACSIS correlator to search for redshifts from SCUBA sources. This potential project is in a very early phase and has not yet progressed to a feasibility study.

## JCMT Internationally Shared Operations Budget: Outturn FY99/00

		\$k	
1	MAUNA KEA OBSERVATORY		
1.1	Utilities, Telephones	78.4	
1.2	Telescope maintenance, development	199.0	
1.3	Building maintenance, development	30.3	
1.4	Road maintenance, snow clearing	29.8	
1.5	Cryogenics	190.0	
1.6	Receiver maintenance	34.3	
1.7	Computer systems	<u>27.0</u>	
	<b>Subtotal 1</b>	<b>588.8</b>	
2	MID-LEVEL FACILITY		
2.1	Daily lodging at Hale Pohaku	124.1	
2.2	Library	5.5	
2.3	Visitor Centre, Emergency services	<u>16.2</u>	
	<b>Subtotal 2</b>	<b>145.7</b>	
3	SEA-LEVEL FACILITY		
3.1.1	Office equipment	19.6	<b>notes:</b> <b>1</b> Totals do not necessarily add due to rounding errors
3.1.2	Hilo telecoms	17.9	
3.1.3	Hilo utilities	52.6	
3.1.5	Administration	5.9	
3.1.6	Publicity	9.0	
3.1.7	Safety, etc	13.0	
3.1.11	Lab equipment/storage	5.3	
3.1.12	Library	13.0	
3.1.13	Building maintenance	34.9	
3.2	Vehicle procurement & maintenance	63.4	
3.3	Computer systems	97.3	
3.4	Computer communications	33.9	
3.5	Instrument projects	<u>15.6</u>	
	<b>Subtotal 3</b>	<b>381.5</b>	
4	STAFF COSTS		
4.2	Locally recruited staff	1,820.5	(gross before receipts)
4.2.1	Director	133.6	(gross before receipts)
4.3	Consumables/Travel/Conferences/Training	<u>91.6</u>	
	<b>Subtotal 4</b>	<b>2,045.7</b>	
5	JCMT Fellowship	<u>78.9</u>	
	<b>Subtotal 5</b>	<b>78.9</b>	
6	IPMG SUPPORT		
6.1	Scientific Admin, travel	<u>21.3</u>	
	<b>Subtotal 6</b>	<b>21.3</b>	
	<b>TOTAL</b>	<b>\$3,261,862</b>	
	Allocation	\$2,480,000	
	Receipts	<u>\$809,201</u>	
	Difference from Board Allocation ( <b>underspend</b> )	\$27,339	

## **5. Financial Statement**

Financial statements are given for the Internationally Shared Operations Costs and for the Development Fund. The statements give information on the outturns for the financial year ending 31 March 2000 (FY99/00). The partners contribute to these costs in the proportion UK (55%), Canada (25%) and the Netherlands (20%).

Staff costs of the separate partner countries are not shown, on the understanding that the partner countries contribute staff at their own cost in approximately these proportions.

### **5.1 Shared Operations Costs**

The costs are divided into subtotals associated with the telescope facility on Mauna Kea, the mid-level facility at Hale Pohaku, staff costs, the JCMT Fellowship and the Instrument Project Management Group (IPMG) support. The staff costs shown correspond to the cost of the local staff employed primarily by the Research Corporation of the University of Hawaii (RCUH).

The dollar allocation comprises the Board allocation of \$2,480k plus the dollar receipt total amounting to \$809.201k. These result in available funds of \$3,289.201k.

The dollar receipt figure in the table includes: payment by partners of \$701.1k in lieu of staff; payment by PPARC of \$43.291k for unshared component of Director, \$46.487k for Jane Greaves unshared effort, and \$7.669k for Elese Archibald unshared effort; and payment by Gemini of \$10.654k for shared staff effort.

The outturn figure was \$3,261.862k, resulting in an underspend of \$27.339k, which is to be carried over into FY00/01.

### **5.2 Development Fund**

The primary purpose of the Development Fund is to provide front-rank receivers, bolometers and spectrometers for the JCMT, and to enhance the facility. It is expected that in the long term the partner countries will receive funds in proportion to their contributions.

The allocation for FY99/00 was £480k. This comprises £350k from the Development Fund annual contribution from the partners plus a sum of £130k repaid by PPARC from the 'carry-overs' held by PPARC. Progress on project expenditure was disappointing, particularly so for ACSIS and HARP-B, giving an outturn for FY99/00 of only £296.4k, an underspend of £183.6k.

This underspend is needed for carry forward as it is a requirement for the funding of the ongoing strategic plan. Very significant expenditures are scheduled for the major projects (ACISIS, HARP-B, SMA, SCUBA-2) over the next two years. The status of the current carry-over owed by PPARC as at 31 March 2000 is £722.05k.

## JCMT Development Fund — Cumulative Spend

	1999/00 £k	Cumulative £k	% nat.share
UK	142.22	3,205.09	57.73
Canada	22.26	994.16	17.91
Netherlands	18.00	1,352.60	24.36
Shared	113.92	*	*
Total	296.40		

\* In calculating the % national share, the costs in the 'shared' row have been apportioned to UK, Canada, and Netherlands in the ratios 55:25:20.

## JCMT Development Fund — Outturns FY99/00

Approved Projects	Contractor(s)	Approved by Board	Spend to 31 Mar 2000 £k	Outturn FY99/00 £k
RxA3	HIA	\$100.0k	56.60	0.00
Rx E	RAL	\$100.0k	25.40	15.40
Rx upgrades (RxB3)	JAC		1.70	1.20
Rx upgrades (D-band mixer)	JAC		11.20	11.20
SIS Junctions	SRON	245.5kf pa for 3 yrs	256.00	18.00
Broadband mixer design	MRAO	\$42.0k	25.00	0.00
Optics Design	Maynooth	£5.0k pa for 3 yrs	20.00	5.00
SCUBA Ribbon Cable	UKATC		25.10	14.00
SCUBA Phase I upgrade	UKATC		8.90	8.90
SCUBA 2 prep	UKATC	\$30.0k	30.20	23.30
SCUBA 2 prep	JAC			6.90
Surface improvements	JAC	\$206.0k	124.80	0.00
Active surface control project	JAC			39.80
RxH3	JAC	\$95.0k	99.20	12.30
RxH3	MRAO			20.10
RxH3	CLRC			28.50
ACSIS	HIA	\$850.0k	181.50	19.50
ACSIS	UKATC			2.60
ACSIS	JAC			29.50
HARP-B	MRAO	\$1481.0k	28.50	20.50
HARP-B	UKATC			4.10
HARP-B	HIA			2.70
HARP-B	JAC			1.20
SMA Interferometry	MRAO/JAC	\$257.0k	0.00	0.00
Instrument Programme Travel	JAC			11.70
<b>OUTTURN TOTAL</b>				<b>£296.40</b>

## Appendix A: Time Allocation - Semesters 99A and 99B

Most proposals come from collaborations, but for brevity only the principal applicants and their institutions (when they submitted the application) are given below.

### Semester 99A (1st February 1999 — 31st July 1999)

Aitken D K, Herts., UK André P, Saclay, France	Submillimetre polarimetric imaging of the central 15 parsec of the Galaxy Probing the origins of the initial mass function: wide-field SCUBA imaging of the L1689 dark cloud
Aragón-Salamanca A, Cambridge, UK Barger A, Hawaii, HI, USA	Molecular gas content of star-forming galaxies in nearby clusters SCUBA observations of a sample of optically faint micro-Jansky radio detections
Barthel P D, Groningen, Netherlands	Star forming QSO host galaxies
Birkinshaw M, Bristol, UK Bradford C M, Cornell, NY, USA	The Sunyaev-Zel'Dovich effect in clusters with guaranteed AXAF observations SPIFI investigations of the circumnuclear ring
Canalizo E G, Hawaii, HI, USA Carey S J, AFRL, MA, USA Carey S J, AFRL, MA, USA	Dust emission from QSOs Study of dense cores in MSX infrared-dark clouds Dust emission from MSX infrared-dark clouds
Chapman S C, UBC, Canada Chrysostomou A, Herts., UK Clark J S, Sussex, UK Clemens M S, MRAO, UK	Detecting the Sunyaev-Zel'dovich increment with SCUBA SCUBA polarimetry of high mass YSOs Dusty ejecta around hot massive stars NGC4490/85: Ram-pressure stripping of the interstellar medium and star formation history
Cowie L L, Hawaii, HI, USA	Studying the evolution of galaxy formation in the Hawaii deep survey field SSA13
Eales S A, Cardiff, UK Fich M, Waterloo, Canada Fich M, Waterloo, Canada Frail D A, NRAO, NM, USA Gao Y, Toronto, Canada Hall P B, Toronto, Canada Hasegawa T I, St. Mary's, Canada Hatchell J J, UMIST, UK Hogerheijde M R, Leiden, Netherlands Holland W S, JAC, HI, USA	Canada-UK deep submillimetre survey The mass and temperature distribution of dust in the galaxy NGC6524 Dust in M101 Search for 1.3mm counterparts to Gamma-ray bursts Intra-group cold dust/gas concentration and starburst? Dusty star-forming cluster galaxies at $z=1.5$ ? Molecular ions in NGC7027 A search for CS and HCN in inner envelopes of AGB stars Molecular entrainment in bipolar flows The dust-planet connection: A search for dust around the parent stars of extrasolar planets
Iverson R J, UCL, UK Jewitt D, Hawaii, HI, USA Kawabe R, Nobeyama, Japan	Star formation in the environment of high-redshift radio galaxies Albedos of outer solar system objects Follow-up observations of the submillimetre Sunyaev-Zel'dovich effect towards the X-ray brightest cluster RXJ1347-1145
Keel W C, Alabama, AL, USA Klaas U, Heidelberg, Germany Lee C W, Korea Matthews B, McMaster, Canada	Dust masses and clumping properties in overlapping galaxies Very cold dust in the brightest ultra-luminous IR galaxies Radial density structures of starless cores with and without infall asymmetry A continuing polarization study of molecular cloud cores and young stellar objects
Matthews H E, JAC, HI, USA Matthews H E, JAC, HI, USA Matthews H E, JAC, HI, USA McHardy I M, Southampton, UK McMahon R G, Cambridge, UK Mitchell G F, St. Mary's, Canada Mittaz J P D, MSSL, UK	Mapping the magnetic field geometry in the Serpens star forming region $H_2S$ in cold clouds Observations of HDO in cold molecular clouds SCUBA observations of faint X-ray sources: obscured AGN? The contribution of luminous AGN to the submillimetre Universe Submillimetre imaging of star-forming molecular clouds SCUBA observations of Seyfert-1 and Seyfert-2 galaxies: starbursts or orientation effects?
Molinari S, IPAC, CA, USA Moore T, Liverpool JM, UK	Submillimetre morphology of candidate massive Class 0 protostars The luminosity correlation for high mass molecular outflows

Moriarty-Schieven G, JAC, HI, USA	A survey low-intermediate mass YSOs & prestellar cores for the 'blue bulge' signature of infall
Naylor D A, Lethbridge, Canada	Search for tropospheric CO absorption in Neptune
Neiningner N, Bonn, Germany	The galactic and intergalactic cold dust content of NGC4631
Olofsson H, Stockholm, Sweden	Mass loss on the AGB: the importance of C-chemistry in O-rich circumstellar envelopes
Papadopoulos P P, Leiden, Netherlands	Evaluating the C I line as a tracer of starburst activity
Pooley G G, MRAO, UK	Observations of QPO in GRS1915+105
Richer J S, MRAO, UK	A SCUBA survey of star formation in the Perseus molecular cloud complex
Richer J S, MRAO, UK	Excitation and energetics of molecular outflows: testing models of outflow acceleration
Roelfsma P, Groningen, Netherlands	Submillimetre imaging of ultra compact H II regions
Röttgering H J A, Leiden, Netherlands	Dust and the formation of massive galaxies at $z > 3.2$
Rowan-Robinson M, ICL, UK	The UK 8-mJy SCUBA/ISO survey: determining the cosmological evolution of starburst activity
Sanders D B, Hawaii, HI, USA	The nature of the far-infrared background
Scott D, UBC, Canada	SCUBA follow-up of 175 $\mu\text{m}$ ISO sources
Seaquist E R, Toronto, Canada	Mapping of M82 in $^{12}\text{CO}(6-5)$
Smith I A, Rice, TX, USA	SCUBA observations of Gamma-ray burster counterparts
Stacey G J, Cornell, NY, USA	SPIFI investigations of the barred spiral galaxy M83: feeding the nuclear starburst
Stevens J A, MSSL, UK	A SCUBA/VLBA polarization study of the inner jets of compact radio sources
Tamura M, NAO, Tokyo, Japan	Submillimetre imaging polarimetry of the Rho Oph cores
Tielens A G G M, Leiden, Netherlands	The anomalous $\text{D}_2\text{CO}/\text{H}_2\text{CO}$ ratio towards low-luminosity protostar IRAS16293-2422
Tilanus R P, JAC, HI, USA	Submillimetre imaging of the grand-design spirals in M51 and M83
Unger S, QMW, UK	SPIFI observations of starburst and ultra-luminous galaxies: physical conditions in the interstellar medium
van Dishoeck E F, Leiden, Netherlands	Physical and chemical structure of circumstellar disks
Ward-Thompson D, Cardiff, UK	How do magnetic fields affect protostar formation?
Waters R, Amsterdam, Netherlands	Debris disks in evolved binaries
Wilkes B, SAO, MA, USA	Rest-frame far-IR-X-ray spectral energy distributions of $z>1$ quasars observed with ISO
Wilson C D, McMaster, Canada	The dusty interstellar medium of IC10: clues to star formation in the early Universe

### **Semester 99B (1st August 1999 — 31st January 2000)**

Adamson A J, JAC, HI, USA	Emission and absorption polarizations in Heiles 2
Alton P B, Cardiff, UK	Dust beyond the R(25); the impact on observations of high redshift galaxies
Barger A, Hawaii, HI, USA	Deep submillimetre detections of very faint galaxies behind lensing clusters
Bendo G, Hawaii, HI, USA	JCMT observations of bright spiral galaxies
Biver N, Hawaii, HI, USA	Chemical composition of comets 10P/Tempel 2 and P/Machholz 2
Bolato A, Boston, MA, USA	The ISM in NGC891: how closely does it resemble the Milky Way?
Borys C, UBC, Canada	Shallow survey in Hubble Deep Field flanking fields and Groth strip
Braine J, Bordeaux, France	SCUBA observations of NGC4414: tracing the radial variation in dust temperature
Carey S J, AFRL, MA, USA	Temperatures and masses of dust within MSX infrared-dark clouds
Cimatti A, Arcetri, Italy	850 $\mu\text{m}$ photometry of extremely red galaxies: completion of the sample
Cowie L L, Hawaii, HI, USA	Studying the evolution of galaxy formation in the Hawaii deep survey field SSA22
Edge A C, Durham, UK	Search for CO in massive cooling flows
Fich M, Waterloo, Canada	Properties of dust in IRAS-bright early type galaxies
Frail D A, NRAO, NM, USA	Shocked molecular gas in the supernova remnant W44

Gear W K, Cardiff, UK	Deriving gas and dust masses from submillimetre observations: deriving the basic relationships
Gear W K, Cardiff, UK	Dust and gas in spiral galaxies, and the ratio thereof
Greaves J S, JAC, HI, USA	The magnetic field connection between protostars and their parent clouds
Gregersen E M, Caltech, CA, USA	A search for protostellar collapse in late class I sources
Halpern M, UBC, Canada	Measuring the Sunyaev-Zel'Dovich increment with SCUBA
Hasegawa T I, St. Mary's, Canada	Molecules in NGC7027
Hatchell J J, UMIST, UK	Jet/outflow properties from molecular bullets
Henning Th, Jena, Germany	A search for massive protostellar objects towards luminous IRAS sources
Hogerheijde M R, UCB, CA, USA	The morphology of the cloud cores surrounding young stellar objects
Holland W S, JAC, HI, USA	The Vega phenomenon around nearby stars
Isaak K G, MRAO, UK	CO(6-5) emission from the archetypical local interacting system, the 'Antennae' galaxies
Jewitt D, Hawaii, HI, USA	Albedos of distant planetary bodies
Johnstone D I, Toronto, Canada	SCUBA scan-mapping the southern portion of the Orion A molecular ridge
Kramer C, Köln, Germany	The dust grain opacity at submillimetre wavelengths
Kwok S, Calgary, Canada	Carbon chemistry in post-AGB evolution
Lee C W, Korea	Radial density structures of starless cores with and without infall asymmetry
Lumsden S L, Leeds, UK	Dust emission and hidden star formation in starburst galaxies
Maiolino R, Arcetri, Italy	Absorbed AGNs at $z = 0.2 - 1$ : detecting the FIR counterpart of the hard x-ray background
Matthews B, McMaster, Canada	Magnetic fields of starless cores and young stellar objects
Matthews H E, JAC, HI, USA	Determination of the isotopic ratios for carbon, nitrogen and sulfur in Jupiter's stratosphere
Matthews H E, JAC, HI, USA	Rare species as tracers of the chemistry of oxygen-rich circumstellar envelopes
McMahon R G, Cambridge, UK	The contribution of AGN to the submillimetre universe
Meech K J, Hawaii, HI, USA	The physical characteristics of comet space mission targets
Millar T J, UMIST, UK	Testing molecular depletions in continuum clumps
Mitchell G F, St. Mary's, Canada	Submillimetre imaging of star-forming molecular clouds
Moriarty-Schieven G, JAC, HI, USA	A search for millimetre counterparts to gamma-ray bursters
Naylor D A, Lethbridge, Canada	Vertical mixing in the atmospheres of Jupiter and Saturn
Nisini B, Rome, Italy	Observations of the CO 6-5 line from warm and dense shocks around protostars
Oka T, Chicago, IL, USA	A search for interstellar protonated acetylene $C_2H_3^+$
Owen T, Hawaii, HI, USA	A search for $C^{18}O$ on Titan
Papadopoulos P P, Leiden, Netherlands	Deep submillimetre imaging of a very warm and a very cold IRAS galaxy: dust, CO and H I
Petitpas G R, McMaster, Canada	Do gas properties determine the nuclear structure of barred galaxies?
Pierini D, Heidelberg, Germany	Cold dust emission in normal Virgo cluster giant late-type galaxies of different star formation rates
Rawlings J M C, UCL, UK	The true nature of class I sources
Rawlings S, Oxford, UK	A fundamental test of radio source unified schemes
Redman R O, HIA, Canada	The M-type asteroids 16 Psyche and 216 Kleopatra
Röttgering H J A, Leiden, Netherlands	Dust and the formation of massive galaxies at $z > 3.2$
Sanders D B, Hawaii, HI, USA	SCUBA templates: observations of a new sample of intermediate- $z$ (0.5-1.3) ultra-luminous infrared galaxies
Schmidtobreick L, Heidelberg, Germany	Investigation of an extremely cold cloud complex in M31
Seaquist E R, Toronto, Canada	Mapping of M82 in $^{12}CO$ J=6-5
Serabyn G, JPL, CA, USA	Imaging of Saturn's rings at submillimetre wavelengths
Smith I A, Rice, TX, USA	SCUBA observations of gamma-ray burster counterparts
Stanke T, Potsdam, Germany	SCUBA imaging of Orion protostars
Stark R, Bonn, Germany	Deuterium chemistry in young stellar objects
Stern S A, SWRI, CO, USA	Submillimetre brightness temperature measurements of Triton with applications to both Pluto and Triton
Stevens J A, MSSL, UK	A SCUBA/VLBA polarization study of the inner jets of compact radio sources
Thommes E, Edinburgh, UK	The role of dust in extremely red galaxies

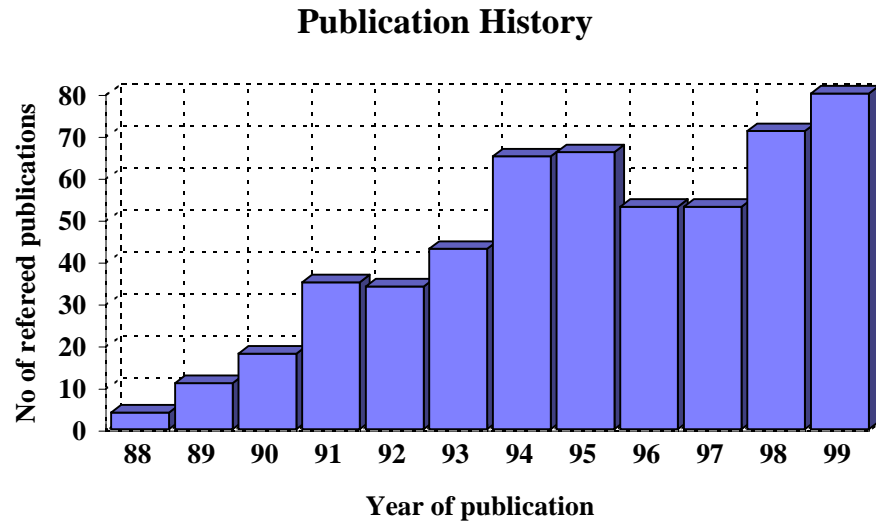
Tielens A G G M, Leiden, Netherlands	Using methanol lines to trace infall
Unger S, QMW, UK	SPIFI investigations of ultra-luminous galaxies
van der Werf P P, Leiden, Netherlands	A deep submillimetre survey in the NTT deep field (continued)
van der Werf P P, Leiden, Netherlands	Completion of the SCUBA survey for distant gravitationally lensed galaxies
van Dishoeck E F, Leiden, Netherlands	Physical and chemical structure of circumstellar disks
Ward-Thompson D, Cardiff, UK	Do magnetic fields influence protostar formation?
Waters L B F M, Amsterdam, Netherlands	Evolution of circumstellar disks in young clusters
Weintraub D, Vanderbilt, TN, USA	Are weak T Tauri stars really diskless?
Wolf-Chase G A, Chicago, IL, USA	Protostellar cores in the Mon OB1 dark cloud
Zhu M, Toronto, Canada	Variation of the $^{13}\text{CO}(3-2)/^{12}\text{CO}(3-2)$ ratio in the 'Antennae' galaxies NGC4038/39
Zuckerman B, UCLA, CA, USA	Size measurements of dusty circumstellar disk in the TW Hydrae association

## UKflex

The UK has continued to allocate formal time to about two-thirds of their nominal quota of shifts. The remaining shifts are designated as 'UKflex' time. These shifts would be added as necessary to pad out high-frequency runs in order to increase the chances of getting these observations completed. A selection of lower-frequency fallback applications were nominated to be observed during these shifts should the weather not be transparent or stable enough for the primary SCUBA project to proceed. The fallback applicants were informed of a maximum number of shifts within which their project might be attempted and were requested to complete observing templates so that the data could be obtained in the service mode.

## Appendix B: List of Publications 1999

This year has seen a total of **82** papers published in refereed journals. The increase over the past two years reflects the significant amount of SCUBA data that have now been processed, analyzed and published. The drop in publications during 1996 and 1997 was primarily due to a decrease in the continuum application total (applicants holding back their UKT14 proposals until SCUBA was available) combined with technical problems and instabilities with the heterodyne instrumentation.



### 1999 Publications in refereed journals

Almaini, O., Lawrence, A., Boyle, B.J.; *The AGN contribution to deep submillimetre surveys and the far-infrared background*; M.N.R.A.S., **305**, L59, 1999.

Alton, P.B., Davies, J.I., Bianchi, S.; *Dust outflows from starburst galaxies*; Astron. Astrophys., **343**, 51, 1999.

André, P., Motte, F., Bacmann, A.; *Discovery of an extremely young accreting protostar in Taurus*; Astrophys. J., **513**, L57, 1999.

Arikawa, Y., Tatematsu, K., Sekimoto, Y., Takahashi, T.; *Shocked molecular gas associated with the supernova remnant W28*; Publ. Astr. Soc. Japan, **51**, L7, 1999.

Barger, A.J., Cowie, L.L., Sanders, D.B.; *Resolving the submillimeter background: The 850 micron galaxy counts*; Astrophys. J., **518**, L5, 1999.

Barger, A.J., Cowie, L.L., Smail, I., Ivison, R.J., Blain, A.W., Kneib, J.-P.; *Redshift distribution of the faint submillimeter galaxy population*; Astron. J., **117**, 2656, 1999.

Bekki, K., Shioya, Y., Tanaka, I.; *Morphological and photometric evolution of ultraluminous infrared galaxies: The nature of faint SCUBA sources*; Astrophys. J., **520**, L99, 1999.

Biver, N., Bockl e-Morvan, D., Crovisier, J., Davies, J.K., Matthews, H.E., Wink, J.E., Rauer, H., Colom, P., Dent, W.R.F., Despois, D., Moreno, R., Paubert, G., Jewitt, D., Senay, M.; *Spectroscopic monitoring of comet C/1996 B2 (Hyakutake) with the JCMT and IRAM radio telescopes*; Astron. J., **118**, 1850, 1999.

Blain, A.W.; *The differential magnification of high-redshift ultraluminous infrared galaxies*; M.N.R.A.S., **304**, 669, 1999.

Blain, A.W., Jameson, A., Smail, I., Longair, M.S., Kneib, J.-P., Ivison, R.J.; *Dust-obscured star formation and AGN fueling in hierarchical models of galaxy evolution*; M.N.R.A.S., **309**, 715, 1999.

- Blain, A.W., Kneib, J.-P., Ivison, R.J., Smail, I.; *Deep counts of submillimetre galaxies*; *Astrophys. J.*, **512**, L87, 1999.
- Blain, A.W., Smail, I., Ivison, R.J., Kneib, J.-P.; *The history of star formation in dusty galaxies*; *M.N.R.A.S.*, **302**, 632, 1999.
- Bloom, S.D., Marscher, A.P., Moore, E.M., Gear, W.K., Teräsranta, H., Valtaoja, E., Aller, H.D., Aller, M.F.; *Multiwaveband observations of quasars with flat radio spectra and strong millimeter-wave emission*; *Astrophys. J. Suppl.*, **122**, 1, 1999.
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- Borys, C., Chapman, S.C., Scott, D.; *Using SCUBA to place upper limits on arcsecond-scale cosmic microwave background anisotropies at 650 microns*; *M.N.R.A.S.*, **308**, 527, 1999.
- Calzetti, D., Heckman, T.M.; *The evolution of dust opacity in galaxies*; *Astrophys. J.*, **519**, 27, 1999.
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## Appendix C: Telescope Performance Statistics

### Weather & Fault Statistics

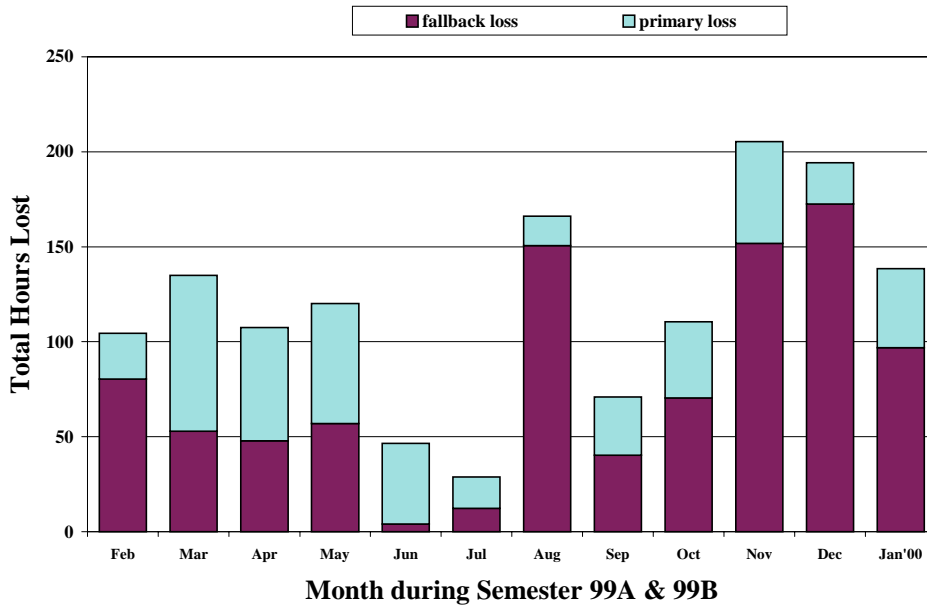
Statistics for both semester 99A and semester 99B are shown in Table C1 and C2 while graphical representation of the data is presented in Figure C1 and C2.

Month (1999)	Hours Available	Extended hours used	Primary programme lost to weather (hours)	%	Fallback programme lost to weather (hours)	%
February	438.5	29.6	104.4	23.8%	80.4	18.3%
March	464.0	18.0	134.9	28.6%	52.9	11.2%
April	464.0	15.3	107.4	23.2%	47.9	10.3%
May	344.0	5.8	120.0	34.9%	57.0	16.6%
June	464.0	23.8	46.5	10.0%	4.0	0.9%
July	472.0	34.6	28.8	6.1%	12.3	2.6%
<b>Total</b>	2,646.5	127.1	542.0	20.5%	254.5	9.6%

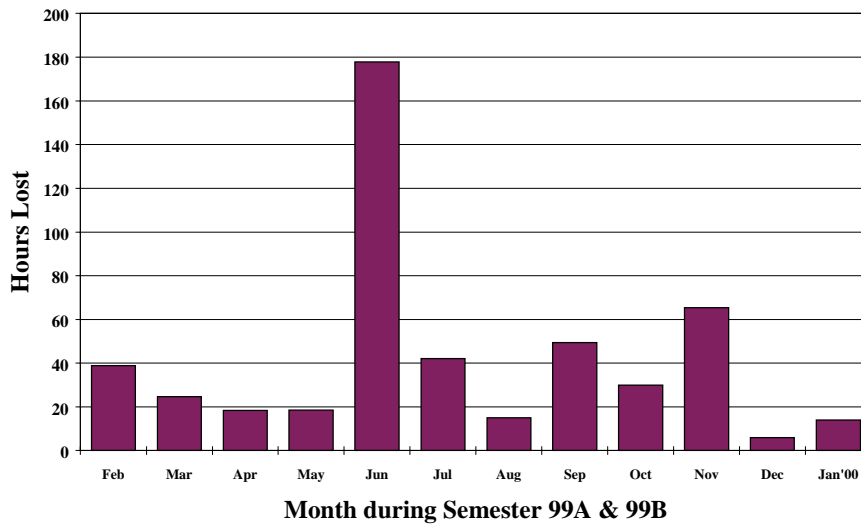
Month (1999)	Hours Available	Extended hours used	Primary programme lost to weather (hours)	%	Fallback programme lost to weather (hours)	%
August	504.0	26.1	166.1	33.0%	150.6	29.9%
September	477.0	12.3	71.0	14.9%	40.3	8.4%
October	474.8	16.2	110.5	23.3%	70.5	14.8%
November	471.5	12.4	205.3	43.5%	151.8	32.2%
December	394.0	15.8	194.2	49.3%	172.5	43.8%
January '00	420.0	28.9	138.5	33.0%	96.9	23.1%
<b>Total</b>	2,741.3	111.7	885.6	32.3%	682.6	24.9%

**Table C1:** JCMT weather statistics for semester 99A & 99B. *Extended hours are observations that run beyond 9:30 am in the morning. At present, extended hours are not used in any of the calculations.*

Figure C1 displays both primary and fallback programme losses. If there had been no flexible scheduling implemented then the number of hours lost each month would correspond to the values at the top of the primary histogram. However, in the event of the weather being too poor to allow the primary project to continue, the flexible scheduling allows a different fallback project to be observed instead. Therefore not as much observing time is lost to weather. In this case, the top of the fallback histogram represents the appropriate number of hours lost to weather each month only.



**Figure C1:** JCMT weather statistics for semester 99A & 99B. See the text for a description of how to interpret this figure.



**Figure C2:** JCMT fault statistics for semesters 99A & 99B.

### Fault Statistics

Figure C2 indicates a total of **12.5%** of the clear time available to programmes (primary plus fallback faults are included) was lost to faults over the reporting period. At present, use of extended hours is not taken into account but is reported for completeness. Figure C2 shows the number of hours lost through faults for each month. The most significant time-loss periods were 24 hours in February due to SCUBA and RxB3 problems; 22 hours in June due to SMU problems and 144 hours due to failure of the carousel drives; 40 hours in September due to

problems with the antenna surface; 26 hours in October due to SCUBA problems; and 64 hours in November due to further SCUBA filter drum trouble. A variety of other RxB3 troubles contributed most of the remaining INS lost time.

Month (1999)	Hours Available	Total	ANT	INS	COMP	SOFT	CAR	OTH
February	438.5	38.9	3.9	23.7	6.9	0.0	3.4	1.1
March	464.0	24.7	1.3	10.7	7.5	2.3	1.0	2.0
April	464.0	18.4	0.7	7.8	2.3	1.9	0.4	5.5
May	344.0	18.5	0.0	15.6	0.5	0.4	0.0	2.0
June	464.0	177.8	22.0	8.6	1.5	0.6	143.7	1.5
July	472.0	42.1	8.5	16.9	0.6	0.1	8.0	8.0
<b>P(hrs)</b>	2,646.5	320.4	36.4	83.3	19.3	5.3	156.5	20.1
<b>B(hrs)</b>		37.7	4.9	11.3	0.8	0.2	20.0	0.5

Month (1999)	Hours Available	Total	ANT	INS	COMP	SOFT	CAR	OTH
August	504.0	15.0	0.5	8.8	0.0	2.8	1.0	1.9
September	477.0	49.4	31.0	4.9	0.2	4.4	0.0	9.0
October	474.8	29.9	3.0	25.7	0.0	0.2	0.0	1.0
November	471.5	65.4	0.0	63.9	0.0	1.4	0.0	0.2
December	394.0	5.9	0.5	0.0	0.0	1.9	1.5	2.0
January'00	420.0	14.0	0.3	8.6	2.4	0.9	0.3	1.0
<b>P(hrs)</b>	2,741.3	179.6	35.3	111.9	2.6	11.6	2.8	15.1
<b>B(hrs)</b>		18.5	0.5	14.1	0.5	0.9	0.0	2.5

**Table C2:** JCMT fault statistics for semester 99A & 99B. Wherever possible the faults are categorized into ANT = antenna; INS = instrument; COMP = computer hardware; SOFT = software; CAR = carousel; with the remainder going to OTH = other. P defines the time lost from primary projects. The category B (hrs) is the time lost to fallback projects. The total time lost to faults during the year is P+B = 556.2 hours.

## **Appendix D: Membership of Board and Advisory Panel**

### **JCMT Board as at December 1999**

#### **Chairman:**

Prof. E. Seaquist                      University of Toronto, Canada

#### **Vice Chairman:**

Dr. W. Boland                      NWO, The Hague, The Netherlands  
Prof. M. Birkinshaw              University of Bristol, UK  
Prof. P.E. Clegg                    Queen Mary & Westfield College, London, UK  
Dr. J.S. Dunlop                    University of Edinburgh, UK  
Dr. D.C. Morton                    HIA, NRC, Victoria, Canada  
Dr. P.G. Murdin                    PPARC, Swindon, UK  
Dr. E.F. van Dishoeck            Sterrewacht Leiden, The Netherlands  
Prof. G.C. Wynn-Williams        University of Hawaii, Honolulu, USA

#### **Secretary:**

Dr. C. Vincent                      PPARC, Swindon, UK

### **JCMT Advisory Panel as at December 1999**

#### **Chairman:**

Dr. J.S. Dunlop                    University of Edinburgh, UK

Dr. M. Fich                        University of Waterloo, Canada  
Prof. W.K. Gear                    University of Cardiff, UK  
Dr. A.G.Gibb                        University of Leeds, UK  
Dr. R.O. Redman                    HIA, NRC, Victoria, Canada  
Dr. J.S. Richer                      MRAO, Cambridge, UK  
Dr. D.B. Sanders                    University of Hawaii, Honolulu, USA  
Dr. R.P.J. Tilanus                    JAC, Hilo, Hawaii  
Dr. P.P. van der Werf              Sterrewacht Leiden, Netherlands

#### **Secretary:**

Dr C. Vincent                      PPARC, Swindon, UK

## **Appendix E: JCMT Staff**

### **Staff list as at December 1999**

(JAC indicates shared between JCMT and UKIRT)

#### **International**

Ian Robson (JCMT, PPARC)

#### **PPARC (JCMT)**

Per Friberg  
Wayne Holland  
Tim Jenness  
Ian Smith  
Graeme Watt

#### **PPARC (JAC)**

Wendy Light  
Lindsay Marcer  
Ian Midson  
Ian Pain

#### **Netherlands (JCMT)**

Fred Baas  
Remo Tilanus

#### **Canada (JCMT)**

Henry Matthews  
Gerald Moriarty-Schieven

#### **RCUH(JCMT)**

Elese Archibald  
Rob Christensen  
Iain Coulson  
Jeff Cox  
Donna DeLorm  
Mary Fuka  
Brad Gom  
Jane Greaves  
Thomas Lowe  
William Lundin  
John Luthe  
Neal Masuda  
Firmin Oliveira  
Peter Oshiro  
Robin Phillips  
Chris Yamasaki

#### **RCUH (JAC)**

Sidney Arakaki  
Tim Chuter  
Vernon DeMattos  
Marjorie Dougherty  
Brian Force  
David Fuselier  
Velvet Gonsalves-Nases  
Sharlene Hamamoto  
Mark Horita  
Nash Kobayashi  
Bernadette Leite  
Junichi Meguro  
Desiree Milar-Okinaka  
Neal Oliveira  
Nick Rees  
Dean Shutt  
Henry Stilmack  
Felisa Teramoto  
Jay Tsutsumi

## Appendix F: Addresses

### JCMT Hawaii:

Joint Astronomy Centre 660 N. A'ohoku Place University Park Hilo, HI 96720 United States of America	Tel: (1)-808-961-3756 (1)-808-935-4332 (answering machine) Fax: (1)-808-969-6591 E-mail: jach.hawaii.edu
Hale Pohaku (general number) JCMT Control Room	Tel: (1)-808-935-7606 Tel: (1)-808-935-0852 Fax: (1)-808-935-5493

### Receiver construction laboratories:

UK Astronomy Technology Centre Blackford Hill Edinburgh EH9 3HJ Scotland, UK	Tel: (44)-131-668-8100 Fax: (44)-131-668-8264 E-mail: roe.ac.uk
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National Research Council for Canada Herzberg Institute of Astrophysics 5071 West Saanich Road Victoria, B.C., V9E 2E7 Canada	Tel: (1)-250-363-0040 Fax: (1)-250-363-8483 E-mail: nrc.ca
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Mullard Radio Astronomy Observatory Cavendish Laboratory Madingley Road Cambridge CB3 0HE England, UK	Tel: (44)-1223-337300 Fax: (44)-1223-354599 E-mail: mrao.cam.ac.uk
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## Appendix G: Miscellaneous Abbreviations

AC SIS	Auto-Correlation Spectrometer and Imaging System
AFRL	Air Force Research Laboratory, USA
ALMA	Atacama Large Millimeter Array, Chile
CADC	Canadian Astronomy Data Centre, Canada
CHAMP-D	copy of the heterodyne array of the MPIfR for D-band
CLRC	Central Laboratory of the Research Councils, Didcot, UK
CSO	Caltech Submillimeter Observatory, Hawaii, USA
DRAMA	Distributed, Real-time Application programming system
FIRST	Far-InfraRed Space Telescope
GSFC	Goddard Space Flight Center, Maryland, USA
HARP	Heterodyne Array Research Programme
HEMT	high electron mobility transistor
HIA	Herzberg Institute of Astrophysics, Victoria and Penticton, Canada
ICL	Imperial College London, UK
IF	intermediate frequency
IPAC	Infrared Processing and Analysis Center, USA
ISDC	Integral Science Data Center, Switzerland
LJMU	Liverpool John Moore University, Liverpool, UK
MIT	Massachusetts Institute of Technology, MA, USA
MPIfR	Max Planck Institut für Radioastronomie, Bonn, Germany
MRAO	Mullard Radio Astronomy Observatory, Cambridge, UK
MSSL	Mullard Space Science Laboratory, UK
MSX	Midcourse Space Experiment satellite, US Air Force
NAOJ	National Astronomical Observatory of Japan, Tokyo, Japan
NEFD	noise equivalent flux density
NFRA	Netherlands Foundation for Radio Astronomy, Dwingeloo
NOAO	National Optical Astronomy Observatories, USA
NRAO	National Radio Astronomy Observatory, USA
NRO	Nobeyama Radio Observatory, Nagano, Japan
ORAC	Observation, Reduction, Acquisition and Control software system
ORACdr	ORAC data reduction software
Perl	Practical Extraction and Report Language
QMW	Queen Mary & Westfield College, London, UK
RAL	Rutherford Appleton Laboratory, Chilton, UK
RCUH	Research Corporation of the University of Hawaii, USA
ROE	Royal Observatory, Edinburgh, UK
RFTM	radio frequency test and monitor system
SIS	superconductor-insulator-superconductor (detector)
SMA	Smithsonian Millimeter Array, Hawaii, USA
SMU	secondary mirror unit
SRON	Space Research Organisation Netherlands, Groningen
SWRI	South West Research Institute, Boulder, CO, USA
Tk	Graphical programming language
TODD	Telescope Observation Designer and Driver
TSS	Telescope System Specialist
UBC	University of British Columbia, Canada
UCL	University College London, UK
UCLA	University of California at Los Angeles, USA
UKATC	UK Astronomy & Technology Centre, Scotland
UKIRT	United Kingdom Infrared Telescope, Hawaii, USA
UMIST	University of Manchester Institute of Science & Technology, UK
YSO	young stellar object