JAMES CLERK MAXWELL TELESCOPE

Annual Report

1996

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

Back cover:

The JCMT and Caltech Submillimeter Observatory (CSO) form an interferometry system.

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Annual Report

of the

James Clerk Maxwell Telescope Board

1996

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Frontispiece: A view of the Nasmyth platform with SCUBA installed. The floor area available on this platform is shown in a photograph in the 1995 Annual Report.

Foreword

by

Professor dr. Harvey R Butcher,

Chairman of the JCMT Board

On behalf of the James Clerk Maxwell Telescope project I have great pleasure in presenting to the national agencies and to the astronomical community the Annual Report for 1996, the ninth full year of operations for the telescope.

The year has been marked by the delivery of two new instruments which together are expected to radically enhance the scientific output of the telescope. SCUBA, once fully commissioned, will provide the most sensitive and flexible bolometer camera in the world, allowing mapping surveys in the sub-mm continuum to be carried out with unprecedented efficiency. Receiver B3 will allow detailed mapping of complex sources in spectral lines at a much enhanced sensitivity. On behalf of the JCMT Board I offer my congratulations to the instrument building teams in the UK and Canada for the delivery of these exciting and innovative instruments.

The next major advance in JCMT instrumentation will be through the construction of a focal plane array operating at B-band (345 GHz). This array will allow rapid spectral imaging with large fields of view. Design work on the first array and digital correlator are now well underway. The addition of this capability is expected to confirm the JCMT's position in the forefront of sub-mm astronomy for some years to come.

Another major advance for the future will be the participation of the JCMT in the Smithsonian Submillimeter Array (SMA), discussions over which are continuing with the JCMT Board's full approval and encouragement. The inclusion of the JCMT within the array is likely to provide considerable sensitivity improvements for objects with small-scale structure such as active galactic nuclei.

Considerable effort has been put into improving the performance of the telescope during the year, particularly with respect to pointing and tracking. Detailed studies of the telescope surface and surface adjustment systems have substantially improved our understanding of the elements which contribute to the accuracy of the surface. It is hoped that these will lead, over the next year or so, to significant reductions in variation arising from the telescope itself.

One of the main scientific highlights of the year was the detection of spectral line emission from the comets Hyakutake and Hale Bopp. Observations with the JCMT illustrated the adaptability of the facility to a broad range of studies and highlighted its complementarity to optical and infrared studies at other facilities, which have also been undertaken during the rare opportunities offered by these two comets.

The considerable success of the telescope during the year may be largely attributed to the efforts of the JCMT staff and particularly the energies of its Director, Ian Robson, and Head of Instrumentation, Phil Jewell. I am sure that the JCMT Board would agree that all the indications are that the progress made in this year will help guarantee an exciting and productive future for the facility.

Introduction

by

Professor Ian Robson,

Director of the JCMT

At last the great day arrived, a day that heralds a new chapter in the story not only of the JCMT, but submillimetre astronomy as a whole. SCUBA, the Submillimetre, Common-User Bolometer Array, was delivered to the JAC in April and as described later in the report was installed on the JCMT after a very short and extremely successful integration and commissioning period in Hilo. Like all major new instruments, SCUBA was not without its teething troubles, but the very first images revealed the dramatic promise of the instrument. Simultaneous imaging of a 2.3 arcminute field of view at two submillimetre wavebands will open up a whole area of new science, hitherto impossible to undertake with single element detectors, or the small size arrays available to date. The rest of the year was completely dominated by SCUBA as we learned to handle its idiosyncrasies, improve the observing efficiency and generally discover how best to use it in various conditions of atmospheric stability and transparency, all working around the need to operate in a flexible scheduling environment. All in all, a very busy and challenging year for the scientific and technical staff. It is also salutary to note that without the presence of three senior members of the SCUBA construction team from ROE for a whole year, we would have been totally overwhelmed with the complexity of the commissioning task.

Although SCUBA dominated the instrumental part of the programme on the telescope, a second major new instrument was also delivered at the very end of the year. This receiver, built by HIA in Ottawa and called RxB3, was a replacement for our venerable 345 GHz receiver RxB3i, also built by HIA and the mainstay B-band receiver on the JCMT since 1991. RxB3 brings dual polarization, state of the art sensitivity, remote and automatic tuning and a host of other user-friendly features. As soon as it was on the telescope RxB3 was seen to have enormous potential for faint lines and for mapping extended regions.

Another major milestone for the JCMT occurred in November when the Board approved a ten-year development plan. This provides for a number of exciting projects: the construction of a 345 GHz heterodyne focal plane array and associated spectrometer; development of sub-arcsecond astronomy through collaboration with the Smithsonian Institute; continuing development of SIS devices and wide-band, tunerless mixers; provision of a new holography receiver to help optimise the JCMT surface; further development of the telescope surface panel actuator system and finite element modelling in order to provide an ‘active’ primary surface to compensate for changing external temperatures and maintain maximum efficiency; a new telescope and antenna control system in order to improve the overall efficiency of photon gathering and data collection;

the upgrading of RxB3i to an interim new 230 GHz-band receiver with much higher sensitivity and increased reliability. Funds are still available for another instrument or for further work on one of the above areas and this will be decided in two years time. Overall, the development plan offers an incredibly exciting programme for the future that promises to keep the JCMT and its user community at the forefront of world submillimetre astronomy well into the first decade of the next Century.

In terms of telescope operations, 1996 was dominated by SCUBA commissioning, and the very poor weather for the year amply demonstrated the requirement for flexible scheduling. The new 24-bit encoders were installed in May and functioned perfectly and provide the potential for sub-arcsecond absolute pointing downstream. Other project work included the installation of a new 6800-based antenna servo micro, the relocation of the secondary mirror unit electronics to the mezzanine platform to make space in the receiver cabin for new instruments, and preparation for the new instruments. Some progress was made on the azimuth track joints, although unfortunately the completion of this project, and a number of other projects had to be postponed due to lack of effort. The introduction of on-the-fly spectral line mapping made a huge improvement in mapping capability for observers, and alongside an enormous increase in data collection rate that had implications for the purchase of new computers and storage media. On the negative side, the old 230 GHz receiver had been plagued by unreliability and was returned to the UK early in the year where a new, and tunerless mixer and a new HEMT amplifier were installed at RAL, giving users much needed improvements in performance and overall reliability.

The scientific achievements during the year were very positive as illustrated by section 1 of this Report. An exciting first was the 460 GHz JCMT-CSO interferometry results, this shows great promise for the future, especially with the new dual high frequency receiver expected in 1997. The oversubscription rate for the first semester of the year remained constant, and talking to a number of users it was clear that many people were awaiting the general call for proposals for SCUBA. When this was announced, albeit in a very limited observing mode, almost akin to a shared risks mode, the oversubscription increased dramatically to over a factor of six.

The financial pressure on operations continues, but the transfer of the instrumentation management group from ROE to the JAC allowed efficiency savings to be made that reduced major squeezes on other parts of operations.

However, without adequate indexation, this gradual erosion of the funding provision will continue to be a problem.

The Prior Options process being undertaken in the UK caused significant effort to be expended by the JCMT management, with some knock-on disruptions to general operations. In addition, the JAC previously had its budget supplied and managed from the Royal Observatory Edinburgh, but from April 1st 1996, the JAC became the primary budget holder receiving its allocation directly from Swindon. This welcomed autonomy however, came with an increased administrative penalty, and as the year progressed this became ever more pervasive. Steps will be sought to modify procedures wherever possible to minimise the additional requirement while maintaining the financial and management integrity required.

1. The James Clerk Maxwell Telescope Facility

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 owned and 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) on Mauna Kea.

The development and operation of the JCMT is overseen by the JCMT Board.

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 utilising 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.

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 sub-millimetre wavelengths,. In addition to providing protection from the wind, the membrane performs the useful function of scattering 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.

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 accommodated on the telescope at the same time and are selected by a moveable tertiary mirror located in the centre of the Cassegrain cabin. The heterodyne receivers, covering the atmospheric windows between 270 and 490 GHz, are mounted in the cabin while the bolometer array instrument, SCUBA, occupies one of the Nasmyth platforms.

Tripartite Agreement

Time Allocation

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. The remaining observing time available 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 applicants from outside the partner countries are assessed and nominated by the ITAC. The JCMT Development Fund provides resources for the development of state-of-the-art instrumentation and for enhancing the capability of the JCMT.

International Agreements

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

The Advisory Panel

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 1996, on May16 & 17 in Halifax, Canada and on November 20, 21 & 22 in Hilo, Hawaii. 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 1996, on May 7 & 8 in London, England and on November 4 & 5 in Groningen, Netherlands.

2. Scientific Report

The highlight of 1996 was the detection of spectral line emission from both of the “Great Comets” of the year, the unexpected Hyakutake and the expected Hale-Bopp. It is not often that detailed examination of these objects travelling from the outer edges of the Solar System towards the Sun is possible. A careful study of their composition can lead to revised and improved theories on the formation and evolution of the Solar System. Comets are believed to be fragments of the protosolar nebula, formed from debris around the Sun prior to the formation of the planets. It is the fact that they are thought to be composed of such unchanged primitive material that makes them extremely interesting to scientists who wish to learn about conditions during the earliest period of the solar system.

Some observations undertaken with the JCMT are reported in summary below together with a selection of other astronomical programmes.

Preliminary results from some of these investigations have been reported in the two issues of the new *JCMT Newsletter* and these along with further 1996 results are summarized here to illustrate the range of investigations underway.

Comet Hale-Bopp

Comet 1995 O1 (Hale-Bopp) was discovered during 1995 July while still well beyond the orbit of Jupiter. Although comets are notoriously fickle, coma activity in Hale-Bopp presently continues to be strong comparable with the Great Comets of the 19th Century. Hale-Bopp therefore seems to present an extremely rare opportunity, and the first such in the modern era of mm/submm telescopes, to investigate a bright long-period comet through all the stages of its development during its passage through the inner solar system.

Observations made in 1995 by *Matthews (JAC), Jewitt & Senay (IfA, Univ. of Hawaii)*, see the JCMT Annual Report for 1995, indicated that Hale-Bopp was undergoing an extremely rapid increase in its carbon monoxide (CO) production rate. It would appear that this was a surge in outgassing in response to increasing insolation, since subsequently the CO output dropped significantly before recovering.

CO is easily released from the water-ice surface matrix, but its vaporization behaviour is quite different from that of other, more complex, trace constituents of cometary ices. One of the goals of their program was therefore to catch the onset of outgassing of different molecules. On 1996 April 8 they managed the first detection of hydrogen cyanide (HCN).

Both the CO and HCN output have continued to be monitored intermittently throughout 1996 as the telescope schedule, instrument availability, and weather has allowed. Some spectra illustrating the development of the line emission are shown in Figure 1.

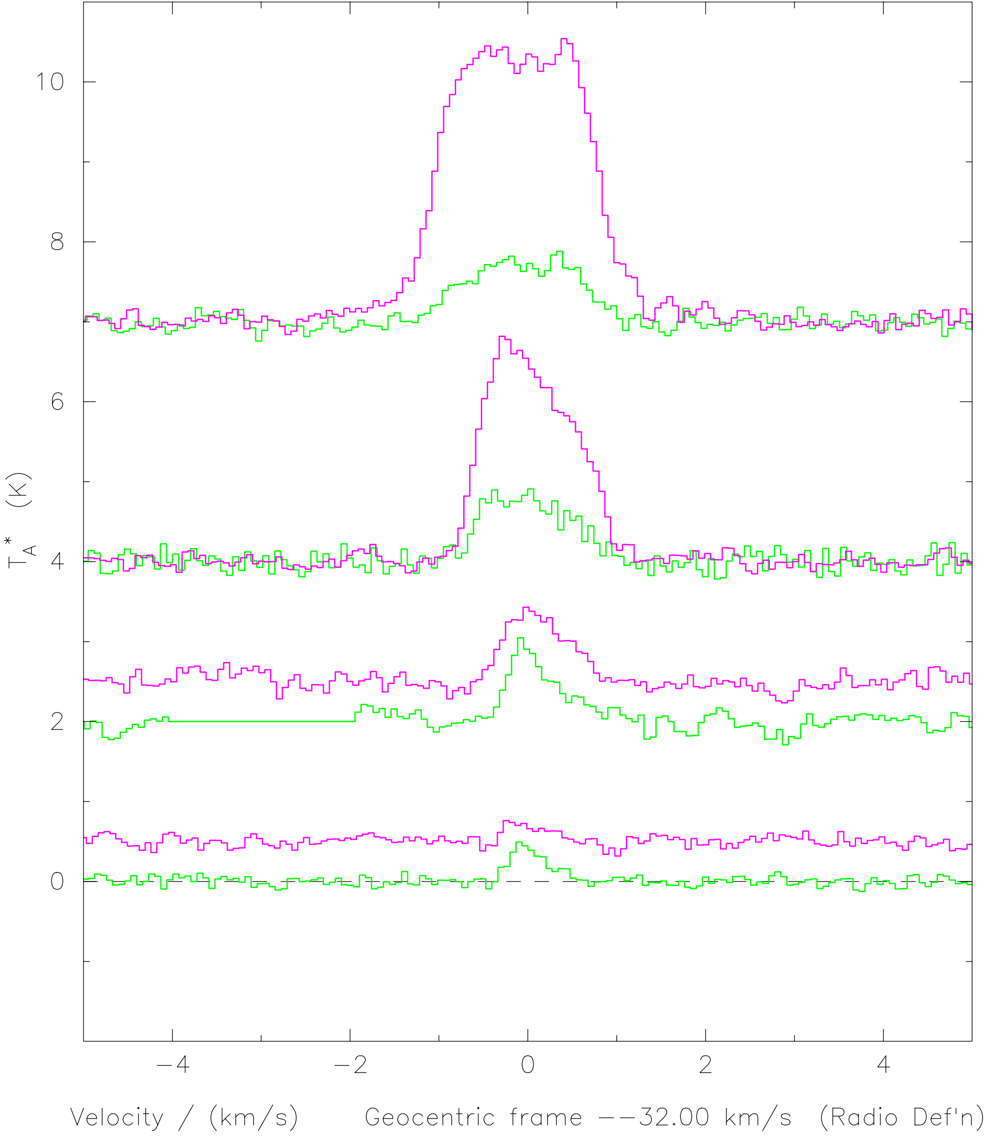


Figure 1: *Spectra of CO (in green) and HCN (purple) observed on four epochs (from bottom to top, 1996 May 17, August 11, and November 30, and 1997 January 18). Spectra are offset vertically from one another for clarity.*

The HCN line has become very much stronger as Hale-Bopp approaches the Sun. There is also a major increase in the widths of both lines. This effect was also seen in Comet Hyakutake during the campaign in Spring 1996.

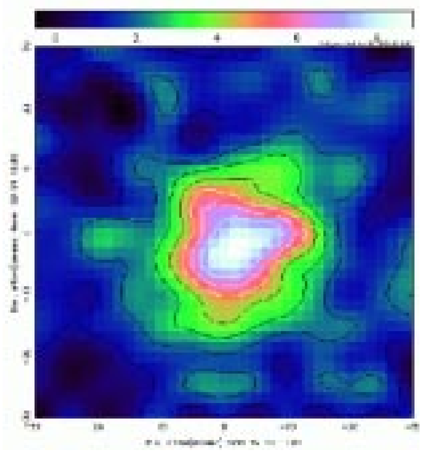


Figure 2: *HCN J=4-3 map of Hale-Bopp.*

The HCN line in Hale-Bopp is so bright that it is possible to carry out mapping observations with very short integration times. A test observation of this type is shown in Figure 2. Such observations are now within the capability of the JCMT and should allow for detailed mapping of the coma out to several beamwidths.

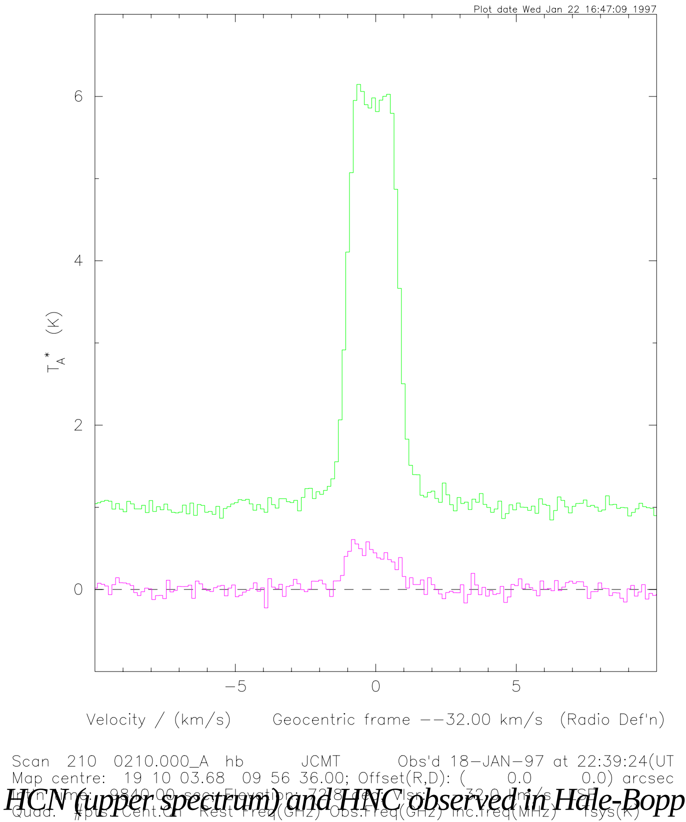


Figure 3: *HCN (upper spectrum) and HNC observed in Hale-Bopp. These data were taken with the new receiver B3.*

It is possible to observe lines from HCN and its isomeric form, HNC, simultaneously with the new receiver RxB3. HNC is a much rarer form of the species. One example of these data is shown in Figure 3. The ratio [HNC]/[HCN] of intensities, typically 6-7%, can be used to argue that the origin of the comet was at a temperature of only a few tens of degrees, consistent with it forming in the cold interstellar medium.

There are some useful experiences gained from the Hyakutake campaign which can be applied to the next phases of the Hale-Bopp programme. On the other hand, there are two major differences which should indicate caution in making such a comparison:

1. Hyakutake was a small comet (its nucleus was less than 3 km in size) whose close approach to Earth happily made mapping observations possible. Hale-Bopp is much larger (40 km, give or take a factor of two), but will never come closer to Earth than about 1.4 a.u (1 a.u. = astronomical unit = the mean distance of the Earth from the Sun = 1.5 x 10^8 km). However, the considerable coma activity of Hale-Bopp is more than likely to compensate for the increased distance. Present line strengths in Hale-Bopp at more than 2 a.u. from the Earth are similar to those from Hyakutake at a geocentric distance of 0.2 a. u.

2. Hyakutake showed a wealth of mm/sub-mm spectral lines while in the vicinity of Earth's orbit, but once subjected to more extreme temperatures close to the Sun, most of the emission faded away. The molecules were being either pushed into higher excitation, or destroyed. In the case of Hale-Bopp there is the more favourable situation that it never gets closer to the Sun than about 0.9 a.u., and for this reason excitation temperatures should remain moderate, and Hale-Bopp should be a strong source of mm/submm spectral line emission throughout the course of the long-term program.

During the early part of 1997, Hale-Bopp moves inbound from 1.4 a.u., through perihelion, and back out again. Within this interval the predominant driver for coma formation is H_2O. The future programme of observations consists of three main sections, aimed at testing models. It is aimed at detailed investigations of the coma by (1) monitoring the line emission characteristics of key constituents, (2) assessing the chemical composition, and (3) determining the dust properties.

This work may result in a subsequent report in the 1997 Annual Report.

Temperature Studies in Molecular Clouds

Accurate observations of the continuum emission from dust particles can result in the determination of a kinetic temperature for the interstellar region under study. These temperatures can vary significantly depending on whether the cloud core has just begun to collapse (and is most likely not much warmer than the ambient material) or whether a protostar has formed deep within the core (which is then heating and evaporating the surrounding dust shroud).

Visser, Richer, Chandler, Padman (MRAO, Cambridge) & Carlstrom (Univ. Chicago) have been studying the properties of dust in the molecular cloud region NGC 2024 (Orion B) using the UKT14 continuum bolometer. This work was conducted in the early part of 1996 before this instrument was physically replaced on the Nasmyth platform by SCUBA.

NGC 2024 is a star forming region in the Orion Molecular Cloud complex and includes a ridge of dense molecular material containing seven compact sources (detected as far-infrared cores). Some of these cores are associated with molecular outflows and probably contain protostars, while others show no sign of star formation and may be even younger objects. The ridge is therefore an ideal location in which to investigate the effect of star formation on the properties of dust in the interstellar medium. The investigators have obtained 800 Tm and 450 Tm maps of the dust emission along the ridge in order to study the way that the temperature is distributed.

Figure 4 shows a spectral index (or colour) map made from the 450Tm and 800Tm observations. It is striking that the ‘spectral index’ value appears lower at the positions of the cores compared with the surrounding molecular cloud. In T Tauri disks the dust component of the spectral index is observed to be lower than the theoretical limit for small grains. This has been interpreted as an evolution of the dust properties, perhaps an increase in grain size in T Tauri disks compared to the interstellar medium. In the case of NGC 2024 the similar decrease in the vicinity of the cores might also suggest a similar evolution of the dust properties.

It is tempting to draw the conclusion that the grain particles are larger in these denser regions. In NGC 2024 there is a good correlation between the dust emission and the molecular gas emission along the ridge, except within a few arcseconds of one of the cores (FIR5), where there is bright dust emission but no molecular gas emission. This discrepancy between dust and gas may be caused by depletion of the gas molecules onto cold dust grains in the dense cold condensations. An alternative explanation is that the temperature of the gas and dust in and near FIR5 is somewhat higher than in the surrounding ridge.

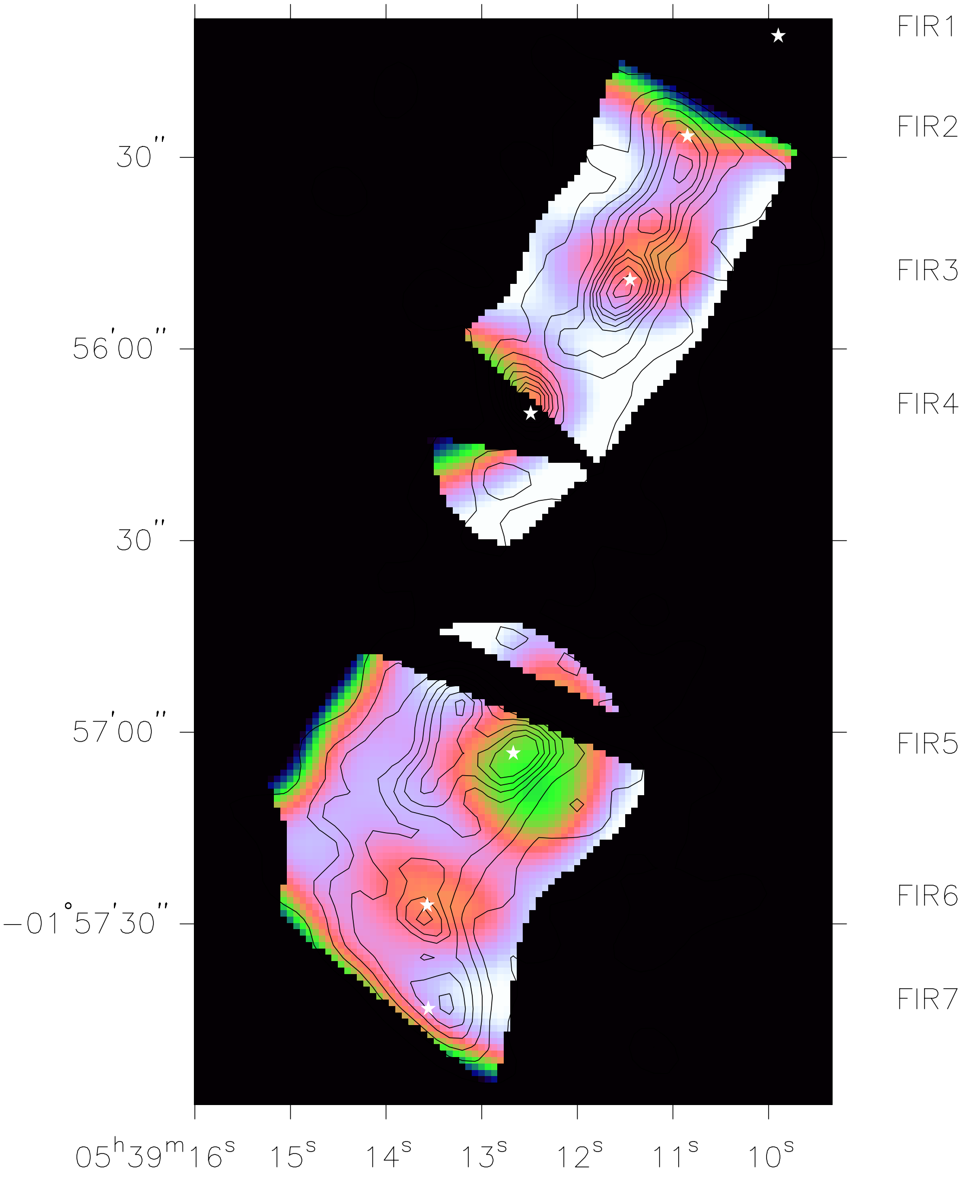


***Figure 4:** Spectral index map from the 450 Tm and 800 Tm continuum images. The contours form the 450 Tm continuum map. The coloured image represents the 850 Tm continuum map. The far-infrared (FIR) peaks, indicating the presence of young pre-stellar objects, are identified by star symbols and cataloged on the right-hand axis.*

High resolution measurements at 50Tm and 100Tm (from aircraft or space) will be essential for determining the spectral energy distributions, and hence the dust temperatures of the individual FIR cores. With SCUBA it should be possible to observe large regions with a higher sensitivity making it possible to study variations of dust properties on larger scales.

Evidence for Protostellar Infall

The excellent angular resolution available with the JCMT has provided the necessary tools with which to investigate the initial collapse phase of a molecular clump. Once the onset of the collapse of a clump of ambient gas has begun, there is a period when the surrounding cloud material is falling onto the core at roughly the same time as the outflow is blowing material away from the core. The spectral signature of the infall is more difficult to detect than that of the ubiquitous outflows.

Recent observations by *Ward-Thompson & Buckley (ROE), Greaves & Holland (JAC) and André (Saclay)* have managed to solve the long-standing problem of disentangling infall from outflow and have identified several sources with protostellar infall. One of these objects lies in the NGC 1333 complex, another well-studied region containing many sites of star formation.

The infall signature usually has a molecular line spectrum that appears double-peaked, with a deep trough between the peaks, and with the low velocity peak significantly stronger in intensity than the high velocity peak, such as shown in figure 5.

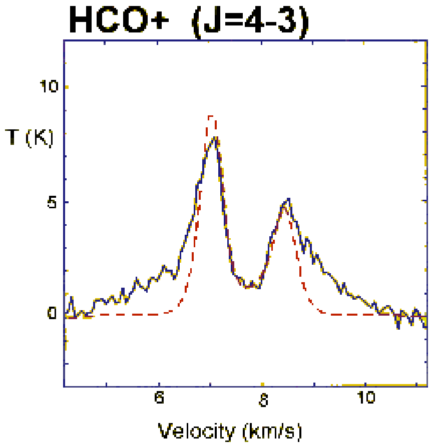


***Figure 5**: Spectra of NGC 1333-IRAS2. This is a HCO^+(4-3) spectrum showing an asymmetric double-peaked structure. The profile predicted by a radiative transfer model of an infalling envelope is superposed (dashed line).*

This is because the gas which is travelling faster away from the observer is collapsing from the near-side of the clump and emanating from the cooler part of the cloud, while the gas travelling less fast from the observer is collapsing from the far-side of the clump and arising from hotter gas closer to the protostar. Our own sun may have formed in this way.

Chemistry of Disks around Young Stars

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

The particular star studied here, TW Hya in the Taurus-Auriga region, appears to possess a compact, dusty molecular envelope that persists despite the general lack of interstellar molecular gas in its vicinity. Most likely the molecular gas orbits the star. Such a relatively gas-rich disk may closely resemble the early solar nebula.

To better understand the chemistry and physical conditions of the circumstellar molecular gas around TW Hya, *Kastner (MIT), Zuckerman (UCLA) & Forveille (Grenoble)* have conducted a molecular line survey with the JCMT. They have detected the numerous transitions of a selection of different molecules: CO, ^{13}CO, HCN, and HCO^+. Spectra of most of these molecular lines are presented in Figure 6. Note the narrow, “wing-less” line profiles, which are unlike those typically observed toward T Tauri stars embedded in molecular clouds.

The relative intensities of the various transitions of CO and HCN suggest that the molecular emission region is rather warm (about 50 K or warmer) and dense (about 10^7 H_2 molecules cm^{-3}). This relatively high gas temperature suggests the emitting region is approximately the size of our solar system, *i.e.*, about 35 times the mean Earth-Sun distance in radius. These intensities indicate that TW Hya is not likely to be much further from Earth than about 30 pc. Its luminosity at this distance is a mere 1/10 that of our own Sun. This distance is consistent with the notion that TW Hya is at a rather advanced age for a T Tauri star. If this distance determination is confirmed, then, at 30 pc, TW Hya would be the closest T Tauri star to Earth that is orbited by a prominent molecular disk.

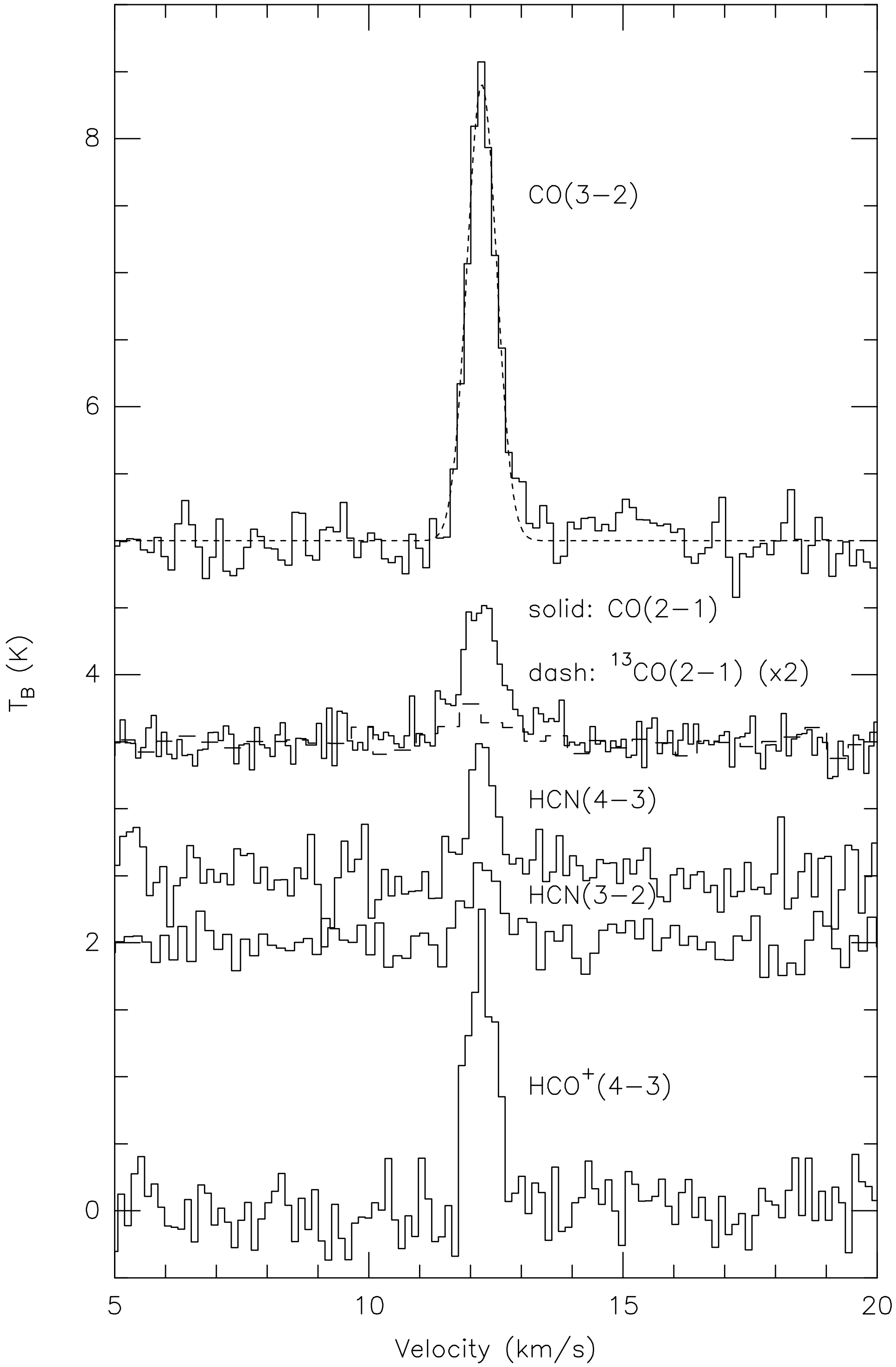


***Figure 6:** Molecular spectra observed toward TW Hya with the JCMT.*

At this distance the angular radius of the disk (about 1 arcsecond) would correspond to the radius of the orbit of Neptune. Such a disk should be marginally resolveable with the next generation of submillimeter interferometers on Mauna Kea, raising the potential for mapping out the gas distribution in a region that corresponds closely with the region occupied by the massive planets in our solar system. From these and other observations at very high resolution, TW Hya may have much more to tell us about how such planets came to be.

Chemical evolution during star formation

The study of the physical and chemical evolution of gas and dust around massive young stars is very well suited to submillimetre telescopes such as the JCMT. Young, hot O and B stars are deeply embedded in molecular clouds during the first 10% of their life and can therefore only be studied at radio and infrared wavelengths. Submillimetre wavelengths are particularly well suited for this purpose because they probe the higher density and temperature gas close to the young stars rather than the ambient cloud material. An important question concerns the chemical response to the physical changes associated with the star formation process such as collapse and outflow activity. Can we find molecules that are particularly sensitive to these physical phenomena so that they can be used as chemical diagnostics, and what is the associated time scale?

Several years ago, *Helmich and van Dishoeck (Leiden Observatory)* started a long-term program at the JCMT to obtain a spectral line survey of three massive young stellar objects in the W3 Giant Molecular Cloud, which is one of the nearest such clouds after Orion. Although high-mass objects such as Orion and Sgr B2 have been studied in detail before, very little systematic work has yet been done on other sources. A survey has the advantage over selected pointings that the physical and chemical conditions are determined in an unbiased way. Moreover, the fact that the three sources originate from the same parent cloud at the same distance facilitates relative comparison and allows a better determination of evolutionary effects. Owing to poor weather during several observing runs, the observations and analysis were finally completed in 1996.

Nearly 90% of the atmospheric window between 334 and 365 GHz has been scanned down to a noise level of ~80 mK, resulting in the identification of several hundred lines per source (see Figure 7). Physical conditions and beam-averaged column densities are derived for up to 22 different chemical species (up to 41 different isotopes). The densities in the three sources are high, $\geq 10^6$ H_2 molecules cm^{-3}, and the kinetic temperatures range from ~55 K for IRS4 to 220 K for W3(H_2O).

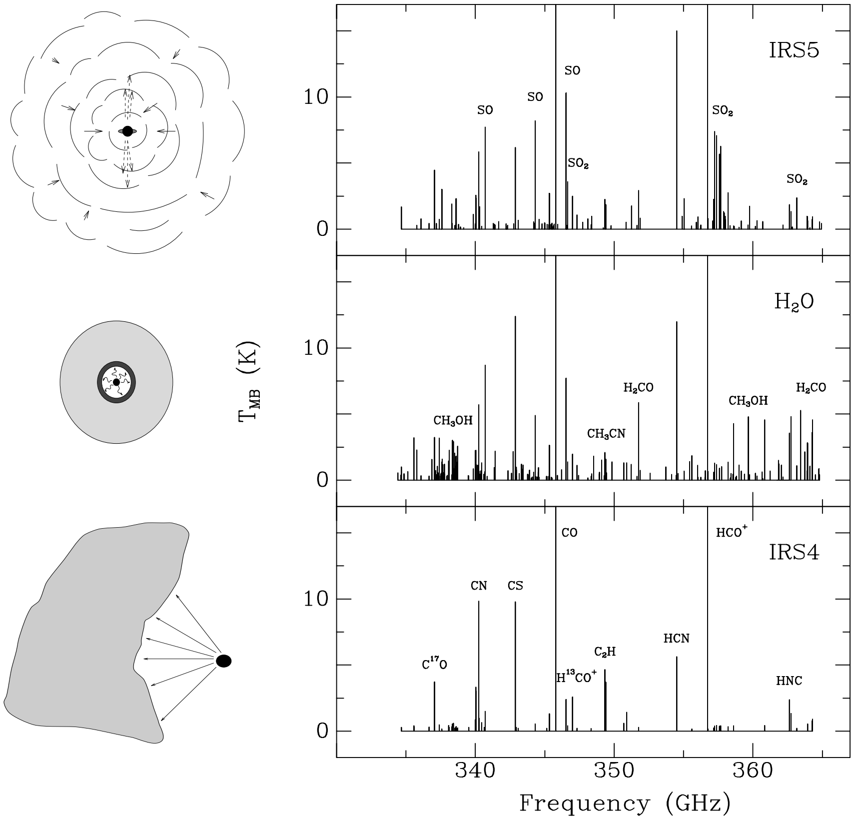


Figure 7: *Summary of the JCMT 335-365 GHz line survey of three massive star-forming regions in the W3 molecular cloud. Strong lines in common in the three spectra are labelled in the W3 IRS4 spectrum only. Large physical and chemical differences are found between the three regions, which are attributed to different evolutionary stages. A possible evolutionary scenario is illustrated by the cartoons and described in the text.*

The chemical differences between the three sources are striking: silicon- and sulfur-bearing molecules such as SiO and SO_2 are prominent toward IRS5, whereas organic molecules like CH_3OH, CH_3OCH_3 and CH_3OCHO are at least an order of magnitude more abundant toward W3(H_2O). Vibrationally excited molecules are also detected toward this source. In contrast, only simple species are detected toward IRS4. The chemical characteristics are interpreted in the context of an evolutionary sequence; IRS5 is the youngest object (about 10^4 yr); W3(H_2O) is somewhat older (~few x 10^4 yr) and in the 'hot core' phase in which molecules evaporate from the grains and drive a complex chemistry; and IRS4 is the oldest object (~ 10^5 yr) and has broken free from its parent cloud.

The survey provides a rich database for other projects. For example, constraints on the amount of deuterium fractionation and the ionization fraction have also been obtained. Specifically, the HDO/H_2O ratio toward W3(H_2O) of 5 x 10^{-4} is significantly lower than the deuteration ratio of other species such as DCN/HCN, suggesting that this cloud never went through a very cold phase. The HDO/H_2 ratio is very similar to that measured in comets such as Hyakutake, providing further support for theories that comets consist of largely unaltered interstellar material.

Molecular Clouds in Other Galaxies

Determining the physical conditions inside molecular clouds is important for understanding the link between the properties of the molecular gas and the types and numbers of stars that are formed. Cloud properties that could affect the star formation process include the temperature and density of the molecular gas, as well as the mass fraction in high density gas.

Wilson (McMaster University), Walker (Univ. Arizona) & Thornley (Univ. Maryland) have used the JCMT to observe the CO molecular line emission in a sample of seven giant molecular clouds in the Local Group spiral galaxy M33. These clouds were chosen to cover a wide variety of star formation conditions, from clouds with no optical (visible) H II regions to a cloud located in the brightest giant H II region in the galaxy.

Star formation can have a knock-on effect, particularly massive star formation, as it can affect conditions inside molecular clouds by compressing the gas through shock waves (from supernovae) and heating the gas by increasing the amount of ultraviolet radiation from starlight. This could either increase or decrease further star formation.

The observers find line ratios for $^{12}CO/^{13}CO$ very uniform, with an average value that compares well with values measured in other spiral galaxies. However, the ratio obtained for one region (NGC 604-2) is significantly

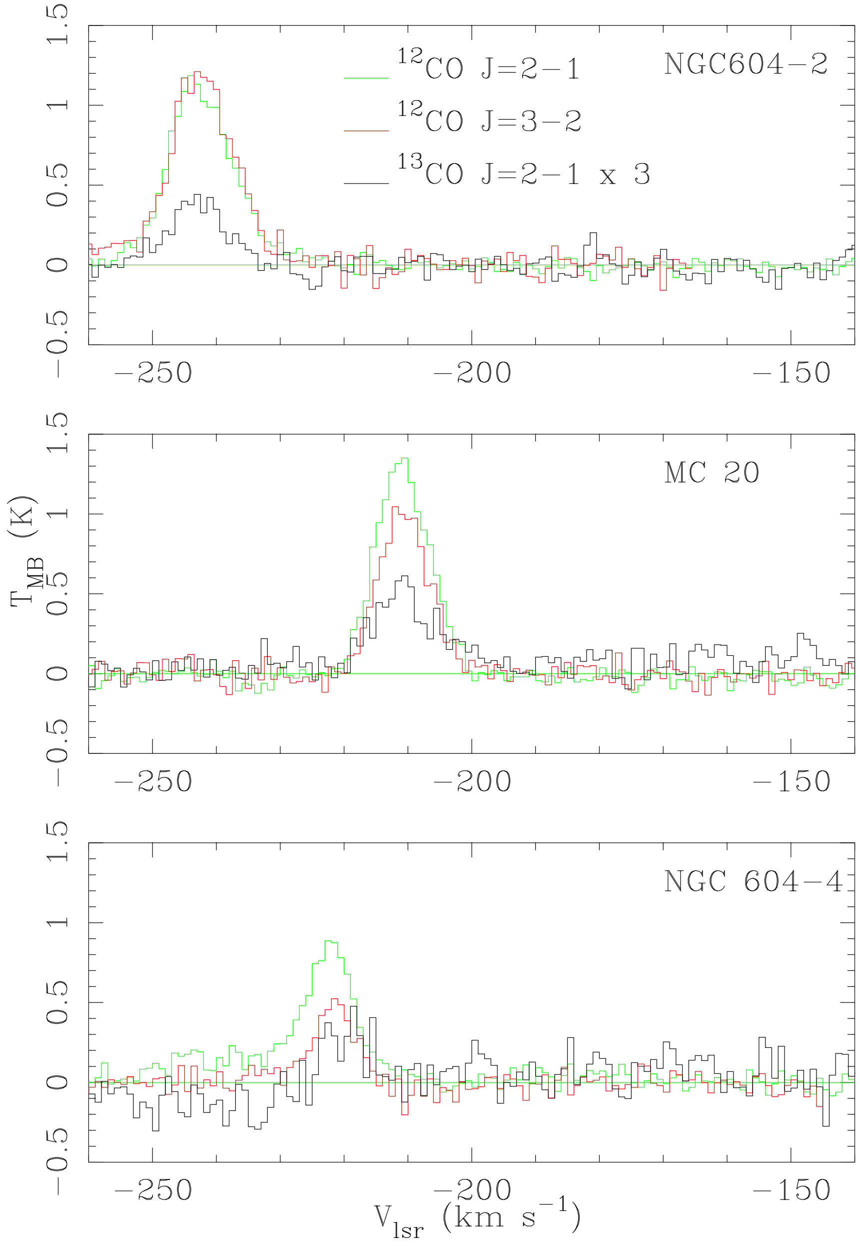


Figure 8: *^{12}CO J=2-1, ^{13}CO J=2-1, and ^{12}CO J=3-2 spectra for three of the seven giant molecular clouds in M33. The spectra are binned to 1 km/s resolution and scaled to the main beam temperature scale. The ^{13}CO J=2-1 spectrum has been scaled up by a factor of 3. Note in particular the varying strength of the ^{12}CO J=3-2 line relative to the J=2-1 line.*

higher than the value for any other cloud. (This higher line ratio is also seen in the nuclei of two other bright galaxies, NGC 253 and M51).

NGC 604-2 is located in the very intense star formation environment of the giant H II region NGC 604.

The difference between clouds in and around this giant H II region is striking. The high line ratio may be a clue to unusual physical conditions in the molecular clouds from which the ionised H II region formed. Alternatively, the high line ratio may be due to heating of the gas by the massive stars in the molecular cloud. Further work is clearly needed to unravel this puzzle.

The data can also be used to show that there is a significant difference in the kinetic temperature (T_K ™ 100 K) in this region compared to the other clouds (T_K ™ 30 K). Thus the large CO line ratio observed here is likely the result of the higher temperature of this cloud. In addition, the NGC 604-2 region may well have a higher density by about an order of magnitude compared to the six other clouds.

The uniformity of the line ratios of the other six molecular clouds observed in the normal disk of M33 suggests that similar observations of molecular clouds in more distant galaxies are likely to produce meaningful measurements of the average physical conditions of the molecular gas. The relatively small effect near the giant H II region NGC 604 suggests that in normal galaxies only the most intense star forming regions may produce significant changes in the molecular gas. It would be interesting to test whether similarly uniform line ratios are observed in individual clouds in the intense ultraviolet field of a starburst galaxy, but such observations must await the construction of an imaging submillimeter interferometer, such as the Smithsonian (sub)Millimeter Array.

3. Operations

This has been another excellent year for general operation, with significant improvements in a number of different areas. At the same time there have been a small number of serious faults that have developed or occurred to many pieces of equipment, ranging from the antenna wheels to the computer disks. The instrumentation has been in a constant state of flux throughout the year: the A-band (230 GHz) receiver having a considerable amount of downtime and requiring significant effort; the B-band (345 GHz) instrument working reliably for most the year and then being replaced in December by its upgraded version; and UKT14, having been the workhorse continuum detection system for the past 9 years, being replaced by its upgraded version, SCUBA, in June. Delivery of the new receiver to cover C-band (460 GHz) and D-band (690 GHz) has slipped to 1997.

Weather & Usage Statistics

The weather and usage statistics for the 12-month period from 1st February 1996 to 31st January 1997 (PATT Semesters 96A and 96B) are compared with values for previous years in the following table. The percentage Fault Loss to Primary Programmes is defined as: Fault Loss / Time Available. Further details can be found in Appendix C. The figures in the table may not add correctly due to rounding and to errors in the earlier datasets. Calculation errors from previous Annual Reports have been corrected here.

	1990	1991	1992	1993	1994	1995	1996
Time Available	75%	85%	77%	79%	74%	82%	74%
Weather Loss	19%	10%	18%	18%	22%	14%	21%
Clear Fault Loss	6.4%	6.4%	6.5%	3.4%	3.7%	4.1%	5.0%

Antenna, Carousel, Pointing & Surface Status

The year started with a failure of one of the antenna drive wheels. This was detected by a 1-2 arcsecond ripple in inclinometry measurements which eventually isolated the fault as residing with the rear right wheel. This was replaced in April. It is probable that the failure occurred on or about Christmas Day 1995.

New 24-bit encoders were installed in May and have performed excellently, putting us in a good position for all-sky sub-arcsecond pointing.

August saw the most ambitious part of the track-levelling project with half the 14 track joints being welded. This project was undertaken because of the high telescope pointing requirements and attempts in 1995 through 1996 to quantify the efficiency with which the track model predicted pointing offsets were regularly plagued by pointing glitches that seemed more than likely due to interactions between the antenna and track joints. The rationale behind the welding was that removing the larger joint steps between the individual sections of the track might at least negate these joint effects. Welding of all track joints will be complete during 1997.

A pointing run two months after the track-welding showed the pointing model was in good shape with *rms* scatters in azimuth and elevation of 1.1" and 1.5", respectively. There was some indication that the results obtained with the heterodyne receivers, earlier in the summer when SCUBA was not available, might have been misleadingly pessimistic.

One of the major goals for the JCMT is maximum performance at submillimetre wavelengths. Therefore considerable effort has gone into measuring and understanding the telescope surface accuracy. Remember the JCMT has 276 panels, each of which is accurate to a *rms* around 12 µm. In fact, the vast majority of the surface work in the first half of 1996 has been associated with the Surface Upgrades Design Study Phase II.

Towards the end of 1995, four dented telescope surface panels were replaced, and attempts continued to improve the surface accuracy. By mid-December a smooth surface had been achieved with a small scale *rms* of better than 16 µm and a total *rms* better than 17 µm. This seemed almost too good to be true and it was then discovered that the holography software was using an incorrect diffraction pattern that distorted the large-scale error of the surface.

A holography run in early January 1996, reduced by the new software, doubled the total error of the surface to 30 µm. This large-scale error was removed in February and reduced the surface errors predicted by holography to 16.4 µm (large- and small-scale errors). A second full surface adjustment was made which removed some of the large-scale residual errors, but left the total errors the same. Without improvements to the holography, panels, and/or the adjuster system, this is about the limit that can be achieved. Taking the known scalloping of the panels into account, predicts a total surface *rms* of about 25 µm.

Night-time holography in mid to late February, obtained to characterise further the telescope in cold night-time conditions and to probe systematics of the holography itself (multi-foci maps), suddenly revealed some large scale astigmatism. The exact cause of this remains unknown, but it may have been due to a severely unbalanced telescope. The telescope was incorrectly balanced after the removal of the Secondary Mirror Unit (SMU) electronics and was correctly balanced at the end of February. A hardware fault was also discovered in the adjuster electronics system which, having been cured, now significantly increases the reliability with which surface adjustments can be attempted.

One of the main sources of surface errors is the limiting accuracy by which the panel adjusters can be set. A number of campaigns were undertaken during the year to obtain the best panel settings and, following the adjustment in August, the *rms* resulting from the adjusters was 16.8 µm. A key test of the adjuster system is to drive alternate panels to different extremes of adjustment, giving the distinctive ‘checkerboard’ pattern shown in Figure 9. The test of the adjuster system is to see how well the smooth surrface is recovered following such a change.

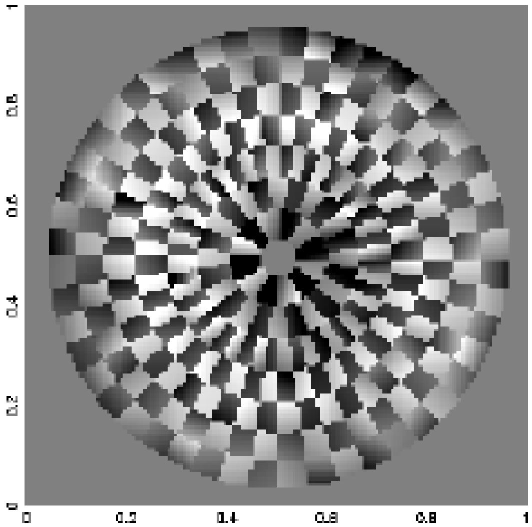


Figure 9: *The surface of the antenna with the adjusters set to produce a checkerboard pattern with the panels..*

Receiver Status

Receiver A2 covers the 210-270 GHz frequency range with a single-polarisation, double-sideband mixer. This receiver is requested by a great many spectroscopists using the 1.3 mm atmospheric window and also serves as the fall-back instrument when the atmosphere is not sufficiently transparent at shorter wavelengths.

This receiver is normally very reliable, but at the end of 1995 it developed a serious noise resonance, a problem that manifested itself only at cryogenic operating temperatures. This fault proved difficult and lengthy to diagnose and solve. In the end, the receiver was returned to RAL where a new (and also tunerless) mixer was installed and the HEMT IF (Intermediate Frequency) amplifier was replaced.

The receiver was brought back into full-time service in November 1996. Since then, it has operated very well, has offered an improved noise temperature (~80 K DSB - Double Side Band temperature) over most of the tuning range, and is generally easy to tune.

The new 345 GHz instrument, RxB3, and the continuum instrument, SCUBA, are described in more detail in the Instrumentation section.

Receiver C2 provides coverage of the 450-500 GHz window with a single polarisation mixer. This receiver has been very reliable all year except for a brief failure of the LO multiplier. This receiver will soon be superseded by RxW which has a much lower noise temperature and has dual polarisation channels. RxC2 will then be converted at RAL to the new 800-900 GHz receiver, RxE.

The DAS is the facility, hybrid-type, digital auto-correlator that is used for all heterodyne spectroscopic observations at the JCMT. The DAS has a number of bandwidth and resolution modes that serve observations of a wide range of astronomical sources, from broad extragalactic lines to the narrow-lines formed in cold, Galactic dust clouds. The DAS has given excellent astronomical results and has performed very reliably all year except for a one-week period in August when it was unavailable following a fault that developed during a maintenance session. The DAS will be the primary spectrometer at the JCMT for at least the next three years.

Short Baseline Interferometry

The JCMT-CSO interferometry had one run in January 1996. Although there were some patches of poor weather, there was a reasonable amount of time when interferometry was possible and there were some stretches of really good weather with the 230 GHz zenith extinction below 0.04 and the ‘CFA submillimetre seeing’ at around 0.2 arcseconds. A range of programmes were carried out at 320 to 356 GHz.

A major effort was made to get the system working properly at 460 GHz for the first time. Since the JCMT has a 4 GHz IF system at this frequency, whereas CSO’s is at 1.5 GHz, it was necessary to introduce additional hardware to convert the JCMT IF to 1.5 GHz. After some effort this was made to work. Observations were made of a number of astronomical objects including the nearby protostars HL Tau and L1551-IRS5, both of which were detected, and the carbon star IRC+10216, from which CO J = 4-3 line emission was detected. The other main technical project on the January run was to try out the prototype 183 GHz radiometer which Martina Wiedner (an MRAO student) had built. The intention is to mount a pair of these on the two telescopes and use them to measure the water vapour content along the paths from the source very accurately so that the phase fluctuations can be corrected on timescales down to a second or so.

Software

The majority of the software group effort for the early period of 1996 was concentrated on continued upgrades to the DAS software, various aspects of telescope control, the off-line systems and the database. Upgrades to the telescope control task to support the new servo micro were completed, and the existing telescope control software was considered to be frozen.

The advent of DAS on-the-fly mapping has dramatically demonstrated the resultant increase in data rates. Development of DAS ‘instrument configuration files’ allows the configuration of the DAS to be read from a file rather than being specified interactively, which greatly simplifies both the use of non-standard configurations and the DAS procedures themselves. The use of wide-band modes through the IF switch unit has also been released. The ‘integrate’ action has been re-written so that readout of the DAS data occurs at the same time as the telescope is moving between phases. This increases the efficiency by 1.6 seconds per cycle for position-switched observations.

A number of minor bugs in the on-line systems have been fixed, including rationalisation of the source velocity prompting scheme, and correction of some long-term (but relatively harmless) bugs in the CONTROL task. Considerable work has been done to the off-line systems, especially utilities and the support for Unix.

SpecX version 6.7 has been released under Unix, which is now the recommended platform for heterodyne data reduction. JCMTDR is also well-supported under Unix and will be the framework within which SCUBA off-line data reduction facilities will be provided. The major observing utilities have all been ported to Unix, and a comprehensive guide to utilities is available through the Web. The JAC discontinued provision of a VMS service for general data reduction on August 1, 1996.

Progress continues to be made with the data archive. All of the data from 1989 onwards has been loaded into the system; prior to this date data files become progressively less compatible, and it has been decided that it is not worth the effort to try to retrieve these data. An archive catalog format has been uploaded to the CADC, and their new Web interface to STARCAT has been released. The database has been reliably archiving new data since the start of semester 95B and now directly stores CSO tau and SAO phase data from the real-time system into the telescope management system. A Canadian co-op student started work in

May to assist in the definition of a complete FITS format which will be compatible between the CADC archive and a new release of SpecX.

As expected, the largest single area of work for the software group over the latter half of 1996 has been support for SCUBA. This has involved the successful integration of the SCUBA observing software to the JCMT telescope and secondary mirror software, commissioning of the various observing modes and considerable development to the off-line data analysis and utility software. Work has also started on a fast data link that will allow the raw data from all pixels to be transferred at the full data-rate for subsequent off-line processing. The software group have also provided extensive support to develop alternative waveforms for the secondary mirror as a work-around to the SCUBA microphonics problem

The bulk of the SCUBA on-line work has been on the continued commissioning of additional observing modes, especially scan-map. After some delays due to hardware problems, the SCUBA fast data-link is essentially complete; it has been tested in the laboratory with simulated data, and should be installed on the telescope in May or June of 1997.

The sole remaining use of VMS is now for telescope and instrument control, where it is expected to remain the existing, stable system for some time.

The summit computer systems suffered from a number of problems between April and July, including problems with the SCSI interfaces, and some problems with faulty disks and memory. Although little observing time was lost, these problems were rather irritating to observers (causing problems accessing data files) and consumed a lot of software group effort.

Little progress has been made on the new Telescope Control System in Hawaii due to the arrival of SCUBA. An investigation has been started to identify possible tools for the planned replacement for the CONTROL task and for other related procedures. As a prototype, a simple graphic user interface to perform calibrations has been developed. This uses Tcl/Tk running on a Unix platform, controlling the existing VMS tasks using networking facilities. This is an encouraging demonstration that it is possible to provide more modern high-level interfaces while retaining the existing underlying instrument control software. Work is progressing on a JCMT FITS format compatible with that under development for the Greenbank Telescope.

The counterpart of the Archive, the Telescope Management System (TMS) continues to perform well. New observations are automatically and instantaneously available to observers on the UNIX computers.

With work on the Archive winding down, emphasis will shift to better exploit the potential of the TMS to support operations and to monitor the environment and technical parameters of the telescope.There were some initial teething problems with IEEE communications with RxB3, believed to be due to a micro/hardware fault; this was cured by improving the error checking in the Vax D-task. Apart from this, integration of RxB3 into the JCMT control system went well.

Jeremy Bailey from AAO has provided the core of the Portable Telescope Control System, and developed a hardware interface simulator and the framework of the compatability-mode TEL task. The route-finding algorithm has been documented and is currently being incorporated into the hardware interface layer. The electronics group are making progress on the EPICS version of the antenna servo (based closely on the UKIRT version) and we hope to perform initial tests of controlling the telescope in late June.

Developments of the TMS to support operations has also progressed; dedicated utilities are now available to plot the CSO zenith extinction and CFA submillimetre seeing as a function of date, plot the receiver temperatures as a function of various quantities, search for and list standard spectra and plot SCUBA noise data of bolometers as a function of date. Further developments to support operations are underway now that effort has been diverted back from implementing the JCMT Archive.

The main goal of the Observatory Control System Upgrade project is to provide more efficient and flexible control of the existing heterodyne receivers, while at the same time providing a framework for control of a future focal plane heterodyne array. Secondary considerations include support for flexible and remote observing, and control of the JCMT as part a linked JCMT-SMA array. Work to date has concentrated on analysising and documenting in detail the current behaviour of the CONTROL task and ICL procedures.

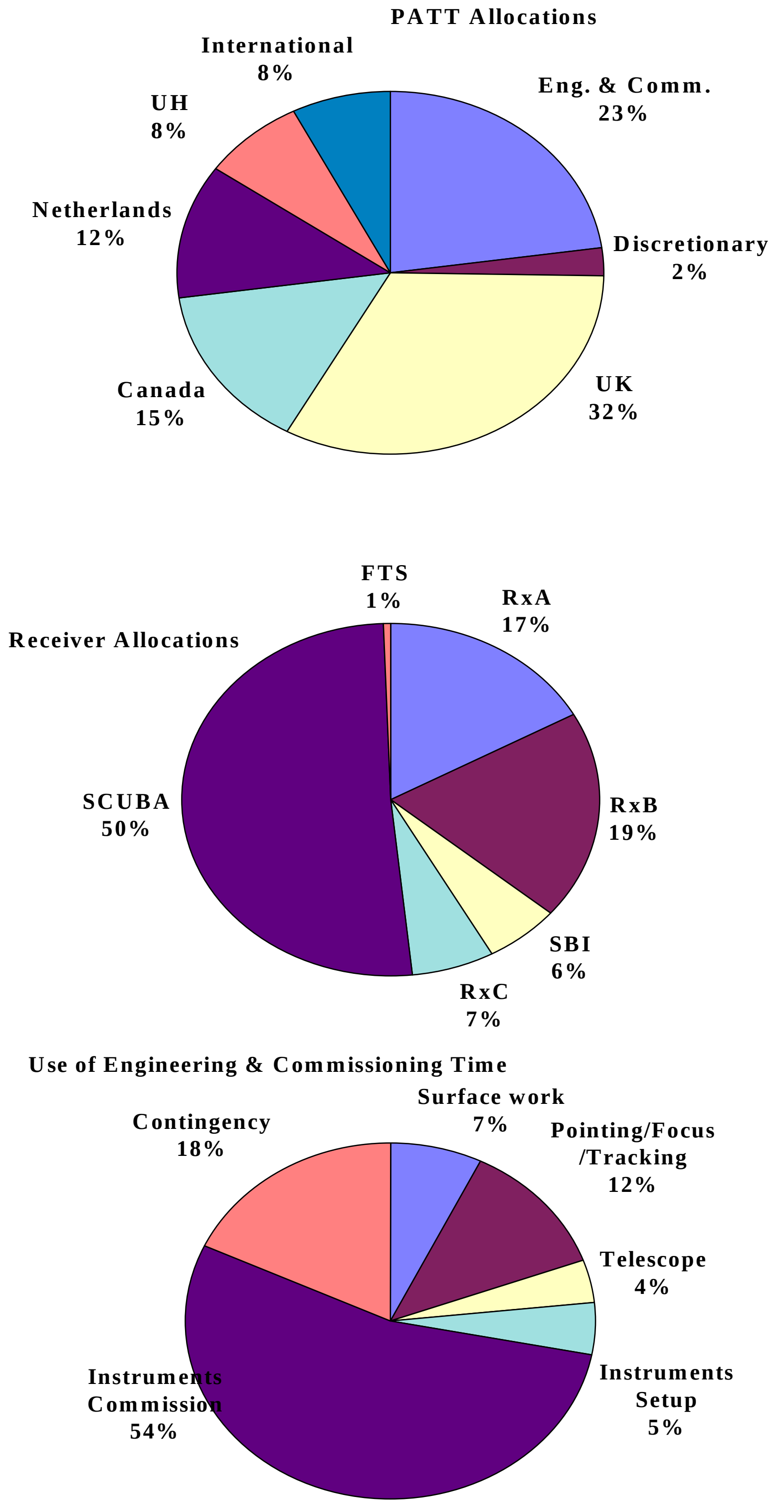


Figure 10: *The Telescope category includes time for receiver calibration & efficiency measures. UKT14 was allocated time in semester 96A. SCUBA was allocated time in 96B but was not available for use. All the SCUBA observations have been postponed; fallback heterodyne observations were undertaken instead.*

4. Instrumentation Programme

This section outlines the status of the JCMT instrumentation development projects and plans. These activities are sponsored by the Development Fund.

Long-Term Development Plan

A detailed plan was put to the Advisory Panel and Board in November. Based on the recommendations from the Advisory Panel and the user community, the JCMT Board subsequently approved the following programme of instrument development.

Receiver Upgrades

Interim A-Band Upgrade -- Conversion of RxB3i to RxA3i. Following the delivery of RxB3, the previous B-band receiver, RxB3i, became available for conversion to another use. RxB3i has been a reliable receiver with a good phase lock system, good cryogenic hold-time, and partially-automated tuning. With relatively minor modifications, RxB3i will provide an excellent platform for a converted A-band receiver. This conversion project is proceeding at HIA.

The upgrade is being done in two phases that are aimed at delivering improved capability to the JCMT as quickly as possible. In Phase 1, only the minimal changes necessary to convert the receiver from the 345 GHz band to the 230 GHz band will be done. The primary work involves reorienting the dewar to fit in another receiver bay at the telescope, installing new A-band mixers, and changing local oscillator components. The mixers are being constructed at HIA but are based on an NRAO tunerless mixer design and utilise University of Virginia niobium SIS junctions purchased on an earlier contract. This work is expected to require only a few months; the converted receiver should be re-installed at the telescope at the end of the summer, 1997.

Phase 2 of the project is aimed at improving the sensitivity and bandwidth of the receiver. New-generation tunerless mixers with improved noise temperatures will be designed and constructed at HIA and the SIS devices will be fabricated at SRON. In addition, the vacuum windows and infrared blocking filters will be replaced with lower loss materials that should improve the receiver temperature. The IF system will be converted from 1.5 GHz to 4 GHz centre frequency which will allow instantaneous bandwidths approaching 2 GHz; this should be an aid to extragalactic observers needing wider bandwidths. A tunerless LO multiplier will be installed to speed tuning and improve reliability. Much of the Phase 2 work requires R&D effort but will be done in the HIA lab without requiring RxA3i to be taken out of service. The IF and LO multipliers will be installed *in situ* at the JCMT in the spring of 1998.

It is expected that the new mixers will be available by the autumn of 1998, and will also be installed *in situ* with minimal receiver down-time.

Mixer Upgrades -- Several programmes for mixer improvements are underway through work with SRON and through design efforts at the Well Found Labs. HIA are designing new mixers for the 230 GHz band as described above and will also begin work on new 690 GHz tunerless mixers. MRAO have a contract for the design of new wideband, tunerless mixers for the 345 GHz band. The SIS devices will be fabricated through the standing contract with SRON. In general, as improved mixers are developed (e.g., with lower noise, wider bandwidth, or improved tuning), they will be retrofitted into the existing receivers.

SIS Junction Programme

The agreement with SRON/RUG for the production of SIS devices was renewed in 1996 for another three years. This fabrication service is available for all the Well Found Labs building mixers for the JCMT. The agreement calls for the accommodation of 3-4 mask sets per year from JCMT groups with reasonable assurance of good performance for all frequencies below 700 GHz. SRON also manufacture junctions for frequencies above 700 GHz on a best effort basis. Whenever possible, mask sets are shared between different JCMT groups to improve production efficiency.

During 1996, SRON/RUG provided additional batches of niobium SIS junctions for RxB3 (~345 GHz) and RxW (~690 GHz). In 1996 November, SRON also completed the reconstruction of their clean room at RUG. These improvements should allow better quality control and throughput of SIS devices. During the coming year, SRON/RUG expects to provide junctions at 800-900 GHz for RxE, at 345 GHz for the wide bandwidth extragalactic receiver, and in the 230 GHz band for RxA3i.

Sub-arcsecond Interferometry

The JCMT Board has authorised JCMT management to pursue a collaboration with the Smithsonian Submillimeter Array (SMA) that should allow the JCMT to become a seamless element of the array sometime around the year 2000. The participation of the JCMT will increase the collecting area of the SMA by ~60% and provide considerable sensitivity improvements for objects with small-scale structure such as active galactic nuclei and compact Galactic dust globules. The added sensitivity should also make techniques such as self-calibration more feasible for the array. For reasons of effort and finance, the decision has been taken to use existing JCMT receivers rather than build a new SMA-style receiver. The receivers will be converted to the same IF centre frequency as the SMA employs.

Capability will be provided for rotating the polarisation angle, for receiving and transmitting LO and IF signals, and for accepting SMA computer commands.

The Director JCMT and the Instrument Programme Management Group have begun discussions with management and technical staff at the Smithsonian Astrophysical Observatory. During 1997 the JCMT expects to establish a Memorandum of Understanding with the SMA that provides a broad outline for the collaboration. Technical meetings with SMA staff are to be arranged and a preliminary design paper will be produced that identifies the changes to the JCMT that are necessary to link with the SMA.

Heterodyne Focal Plane Arrays

The JCMT Board has approved the exciting development of a 345 GHz heterodyne focal plane array and a matching multi-input digital auto-correlator. Instruments of this type enable rapid spectral imaging of large fields of view and make numerous projects feasible that cannot be done in reasonable time with a single-beam system.

The first array receiver will by an 8-element (4x2) array at 345 GHz and will be built by MRAO / Cambridge. The array will be built on a turntable so that it can track source parallactic angle rotation. Special attention will be paid to achieving high performance in each of the mixers so that no significant penalty will be incurred compared to the best single-beam systems. To achieve this, the mixers will be fabricated in horn and reflector antenna assemblies that are cooled to 4 K and do not require correcting lenses. Tunerless mixers will be used to reduce mechanical complexity and tuning time. This project is expected to require about 3 years to construct.

After delivery of this first-phase instrument, another phase may be undertaken that would double the number of elements to 16. This might be accomplished by constructing another bank of elements at an opposite polarisation or by stacking an additional set of mixers on a lower tier. Alternatively, or in addition to the 345 GHz camera expansion, other array receivers may be constructed for the 690 GHz and 230 GHz bands. Choices will be made in about two years and will depend on the financial and staffing situations and the priority given to the various options by the user community.

The Board has also approved construction of a new digital autocorrelator for use with the array receivers, and that project is now underway at HIA. This correlator will be part of the family of correlators based on the Canaris chip and the GBT correlator design. By adopting this approach, the JCMT reduces development time and risk and can participate in collaborations with other institutions following this design. At this time, five observatories are basing correlators on this design.

The correlator will be able to accept 16 IF inputs at bandwidths approaching 1 GHz, or 8 inputs at nearly 2 GHz. Enough digital hardware will be constructed to accept 32 inputs at 1 GHz bandwidth; this expansion could be completed at modest cost and in a practical timescale in the future. Numerous spectral resolution modes will be available, down to about 30 kHz minimum channel spacing. This correlator is being built as an imaging system. It will be capable of fast data dumps for on-the-fly mapping and will include real-time image display software. The project is expected to be completed by the autumn of 2000.

Current Instrument Programme

Two major, new instruments were delivered to the JCMT in 1996, SCUBA and RxB3. RxW is in advanced stages of development.

New Instruments

SCUBA -- ROE/QMW/RAL

SCUBA

SCUBA, the 131-element, multi-wavelength bolometer array, arrived in Hilo at the end of March, 1996. SCUBA consists of a long-wavelength array of 37 pixels, a short-wavelength array of 91 pixels, plus three photometric pixels at 2, 1.3, and 1.1 mm wavelength. The arrays work in filter pairs, 850/450 Tm or 750/350 Tm wavelength and can be used simultaneously. SCUBA is, by far the largest, most sensitive, and most flexible bolometer camera ever built.

SCUBA arrived in Hilo in excellent condition. It was reassembled at the JAC for a round of tests and for training of the local staff in maintenance and repairs. SCUBA was then transported to the JCMT and installed on the Nasmyth platform. After daytime testing for several weeks, first astronomical light was achieved 1996 July 8. The entire phase of delivery, installation, and integration of the JAC staff went extremely well.

Astronomical commissioning commenced in July and in the first instance proceeded relatively smoothly. Control of observatory systems by the SCUBA computer and queued observing worked perfectly. Basic observing modes were checked out and the staff began calibrating the instrument and investigating the effects of sky noise and optimum observing strategies. A few initial astronomical images were quickly obtained.

Soon, however, it became clear that SCUBA’s sensitivity was off target by a factor of two or more at 850 Tm and more in some of the other bands.

Extensive investigations during the late summer and autumn revealed that the bandpass filters had shifted from their designed centre wavelength and had moved, in some cases, well into the atmospheric absorption bands. Interference fringes in the bolometer response were also observed. Investigations into these problems were well underway and there was some progress in understanding them when a serious, new fault developed with the cryogenics in early December: an instability in the base temperature of the 100 mK stage.

Although some months were required for their resolution, we are now pleased to report that almost all of these problems have been solved. The cryogenics problem was caused by an apparent vacuum leak in the circulation pump that only manifested itself in very cold ambient temperatures. The filter bandpass shifts were caused by cryogenic warping in the large mounting rings of the filters and have been remedied through the diligent effort of the staffs at QMW and at the JAC. Some small efficiency losses are still present, but the overall sensitivity of SCUBA is within very acceptable ranges now. The objective of achieving a factor of 10,000 speed-up in dual-band imaging over UKT14 has been achieved. Final commissioning is proceeding at this writing and SCUBA appears to be well on its way to becoming a smoothly-functioning, and revolutionary astronomical instrument.

RxB3

RxB3 -- HIA/SRON/RAL

RxB3 is a new common-user receiver for the 345 GHz band constructed principally at HIA using SRON junctions. It was delivered to the JCMT in November 1996 and installed on 1996 December 3. This receiver provides a factor of 4-8 increase in observing speed compared to its predecessor, RxB3i, depending on weather conditions. This speedup is achieved through three main enhancements. First, the receiver noise temperatures are below 100 K (DSB), down from ~160 K in RxB3i. Secondly, the receiver has two orthogonal polarisation channels, and third, it has a single-sideband filter that terminates on a cold load. The sideband filter improves calibration and also rejects the atmospheric noise in the image sideband.

RxB3 is also the first JCMT receiver to offer fully-automated tuning. By supplying the frequency, sideband, and issuing the appropriate command, the JCMT and receiver computer systems will then tune the receiver using a combination of look-up tables and peaking algorithms. This capability avoids, among other things, the necessity of parking the antenna at zenith and a trip to the receiver cabin by the telescope operator each time a tuning change is required.

Status of Instruments under Construction

RxB3 has been used extensively in its first few months on the telescope. The receiver has suffered a number of teething problems owing to its complexity and advanced capabilities and also to personnel changes and the relocation of the home lab at HIA. Reliability is steadily improving, however.

RxW

RxW -- MRAO/SRON/Maynooth

RxW is the new, dual-band receiver covering the 450-500 GHz (C-band) and 630-710 GHz (D-band) atmospheric windows. This receiver has dual polarisation channels in each band — 4 mixers total — and a single-sideband filter terminated in a cold load. One can switch between the two bands quickly. The 500 GHz mixers were designed at MRAO and the 700 GHz mixers at SRON; both mixers have SRON niobium SIS junctions. RxW uses a 4 K, closed-cycle cooler, the first of its type to be used on a JCMT receiver.

The improved mixer performance in the 500 GHz band, the dual-polarisation channels, and the image sideband rejection will result in a substantial improvement in observing speed compared to the existing C-band receiver, RxC2. The 700 GHz capability will provide the first common-user receiver for the JCMT in this band. With this receiver, the JCMT will have access to the J=4-3 and J=6-5 CO transitions, as well as the 492 GHz transition of C I.

All mixers are now installed in the main RxW cryostat and construction is complete on all aspects of the receiver. The receiver is undergoing laboratory commissioning and debugging at this writing. A summer 1997 telescope commissioning is planned.

RxE

RxE -- RAL/UKC/HIA/SRON

In this project Receiver C2 (460-492 GHz) is to be converted to a 800-900 GHz receiver for the observation of the 809 GHz C I line, the J=7-6 CO line at 807 GHz, and the isotopes of J=8-7 CO near 880 GHz. This project is approved and mixer development is underway at RAL and HIA. The main part of the project awaits the return of RxC2 which will occur when RxW is commissioned on the JCMT. The project will take about one year to complete after the return of RxC2.

Water-Vapour Radiometer

Water-Vapour Radiometers -- MRAO/RAL

MRAO has built two water vapour radiometers, one for the JCMT and one for the CSO. These units operate near the 183 GHz water transition. The instruments measure the atmospheric emission at frequencies on and either side of the water resonance.

This information is then input to atmospheric models that can produce the zenith atmospheric opacity as a function of frequency. By comparing continuous results from the JCMT and CSO water vapour radiometers and again applying atmospheric models, one can derive the time-variable phase offset between the two telescopes at a particular observing frequency. This information can be used to correct phase errors during short-baseline interferometry between the JCMT and CSO. This project is of practical interest to the JCMT and CSO but is also an important research project of relevance to millimetre-wave and submillimetre-wave interferometers world-wide that are seeking methods to improve phase coherence during observations.

The radiometers were installed on the JCMT and CSO in November 1996 and used on a test basis during an interferometry run at that time. They have since undergone further refinements at MRAO and are expected to return to Mauna Kea on a permanent basis in May 1997.

Innovative New Projects

Three JCMT development projects have been funded under the "Innovative New Projects" initiative.

Investigation of the Design of SIS Receivers for Submillimetre-Wave Extragalactic Astronomy -- MRAO

MRAO is conducting a design study of wide bandwidth, tunerless SIS mixers that will be tailored for extragalactic spectroscopy. The thrust of the project is to prototype a low-noise, B-band (345 GHz) SIS mixer with a bandwidth in excess of 2 GHz. This work is the first step toward the creation of a wideband, extragalactic array receiver.

A Common-User Polarimeter for SCUBA -- QMW/ROE/Maynooth/HIA/Japan

Work is underway to supply SCUBA with a state-of-the-art submillmetre polarimeter. Two achromatic waveplates have been purchased, one covering the array wavelengths (350-850 microns) and the other the photometric pixel wavelengths (1.1—2.0 mm). The waveplates are expected to be delivered to QMW (Univ. of London) by the end of April 1997. QMW will test the waveplates in their lab, using a recently manufactured spinner module. It is planned to commission an interim polarimeter on SCUBA at the start of semester 97B. This instrument will work with the centre pixels of each array simultaneously, or any of the photometric pixels individually. It will be an interim instrument in the sense that only single-pixel work will be initially attempted, and the complete SCUBA data acquisition system will not be used. The commissioning will allow measurements of instrumental polarisation, and tests of the best way to take data. It is envisaged that the interim instrument will be offered to the community in a service mode (similar to the arrangement for SBI). Concurrently with the interim instrument availability, effort will concentrate on developing the necessary algorithms to allow multi-pixel (mapping) polarimetry at the array wavelengths. The timescale for the complete instrument is currently mid 1998.

JCMT Internationally Shared Operations Budget: Outturn 1996/97

		$k
1	MAUNA KEA OBSERVATORY	
1.1	Utilities, Telephones	76.8
1.2	Telescope maintenance, development	68.6
1.3	Building maintenance, development	27.5
1.4	Road maintenance, snow clearing	21.0
1.5	Cryogens	183.1
1.6	Receiver maintenance	26.1
1.7	Computer systems	7.0
1.8	Projects	192.8
	subtotal 1	**602.9**
2	MID-LEVEL FACILITY	
2.2	Daily lodging at Hale Pohaku	123.1
2.3	Library	13.0
2.4	Visitor Centre, Emergency services	12.2
2.5	Computer systems	0.4
	subtotal 2	**143.3**
3	SEA-LEVEL FACILITY	
3.1.1	Office equipment	21.4
3.1.2	Hilo telecoms	15.4
3.1.3	Hilo utilities	44.6
3.1.4-9	Post/admin/safety/etc	40.9
3.1.6	Publicity	14.4
3.1.11	Library	14.4
3.1.12	Building maintenance	37.3
3.2	Vehicle procurement & maintenance	82.5
3.3	Computer systems	90.3
3.4	Computer communications	19.8
3.5	Projects	37.1
	subtotal 3	**418.3**
4	STAFF COSTS	
4.2	Locally recruited staff	1,669.1
4.2.1	Director	106.7
4.3	Consumables/Travel/Conferences/Training	99.3
	subtotal 4	**1,875.2**
5.1	JCMT Fellowship	55.0
	subtotal 5	**55.0**
6	IPMG SUPPORT	
6.1	Scientific Admin, travel, interactive management	39.0
	subtotal 6	**39.0**
	TOTAL	**$3,133.6k**
	Allocation	$2,550.7k
	Receipts	$662.6k
	Difference from Board Allocation **(underspend)**	$79.7k

notes:

1. subtotals do not necessary add within headings due to rounding errors

2. some totals are offset by receipts not shown in these tables

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 year ended 31 March 1997. 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.

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 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 $2,464.126k plus the carry-over from operations from 1995/96 of $86.567k — this latter amount comprising carry-overs from the dollar lines of $52.663k and the now extinct pounds line of $33.904k. These result in available funds of $2,550.693k.

The dollar receipt figure in the table includes: $189.242k from the Development Fund for facility development and upgrade projects; payment of $344.5k by Parties in lieu of staff; and a payment of $128.855k by PPARC for staff shortfalls during 1994/95 and for the Director JCMT JAC share for 1996/97. This results in an overall underspend of $79.7k.

Development Fund

The JCMT Development Fund is funded at a level of £500k per annum. The partner countries contribute in proportion UK (55%), Canada (25%) and the Netherlands (20%).

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 of £678,446 takes into account the underspend of £178,446 in 1995/96. The outturn of £446,400 thus gives an underspend of £232,046.

JCMT Development Fund — Cumulative Spend

	1996/97 £k	Cumulative £k	% nat.share
UK	140.97	2793.48	59.89
Canada	8.75	765.28	16.41
Netherlands	121.32	1150.41	23.70
Shared	175.36	*	*
Total	446.40		

* 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 1996/97

Approved Projects	Prime Contractor	Approved by Board	Spend to 31/3/97 £k	Outturn 1996/97 £k
✏ *Current Projects*				
Rx B3 - completed	HIA	£233.0k	228.50	8.75
SCUBA	ROE	£911.1k	920.83	93.42
Rx W	MRAO	£332.5k	325.20	0.00
RxA3i (A2 conversion)	HIA/JAC	$100.0k	9.64	9.64
D-band Mixer (add. 3rd block)	SRON	£27.6k	32.71	8.92
SIS Juncs - 1/4 yr. under old contract	SRON	£215.5k	236.95	34.35
- 3/4 yr. under new contract	SRON	245kf pa	78.05	78.05
Optics Design - original contract	Maynooth	£20.0k	20.00	5.00
- extension	Maynooth		5.00	5.00
Focal Plane Array - Correlator	HIA/ROE		45.79	45.79
JCMT-CSO Radiometers	MRAO	$95.0k	51.02	15.22
✏ *Innovative New Projects*				
Broadband mixers	MRAO	$42.0k	12.00	12.00
SCUBA polarimeter	QMW	£20.0k	10.33	10.33
Rx E (C2 conversion)	RAL	$100.0k	0.00	0.00
✏ *Other Authorised Spend*				
JAC Facility upgrades ($189.24 @ 1.5779)				119.93
		OUTTURN TOTAL		**446.40**

Appendix A: Time Allocation - Semesters 96A and 96B

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

Semester 96A (1st February 1996 — 31st July 1996)

Avery L W, JAC, Hawaii	Chemical asymmetries in L1157? - What's the real story?
Avery L W, JAC, Hawaii	A study of the kinematic and density structure in Rho Oph C
Bastien P, University of Montreal	Submillimetre polarimetry of protostellar disks
Boogert A C A, Univ. of Groningen	Physical conditions & carbon budget around YSO's with ice bands
Burton W B, University of Leiden	CO J = 3-2 observations of the nuclear disk in Cen A
Carpenter J, University of Hawaii	An unbiased survey for massive dense cores
Carpenter J, University of Hawaii	Properties of massive dense cores
Clark T A, University of Calgary	Limb distribution & mapping of HI n = 19-20 emission on the Sun
Davies J K, JAC, Hawaii	Molecular content of Comet P/Honda-Mrkos-Pajdusakova
Davis C J, Max-Planck, Heidelberg	Jet-driven molecular outflows: Prompt or turbulent entrainment?
Davis G R, University of Saskatchewan	Brightness temperature spectrum of Jupiter
De Jong T, University of Groningen	Mapping the C I envelope of IRC + 10216
Dent W R F, JAC, Hawaii	Statistics of YSO outflows
Duley W W, University of Waterloo	Search for TiO in two star-forming regions
Evans A S, University of Hawaii	Submillimetre spectroscopy of $0.02 < z < 0.1$ powerful radio galaxies
Feldman P A, HIA, Canada	Continuum of the S233 outflow region associated with a methanol maser
Fich M, University of Waterloo	Dense molecular gas in the NGC 2264 G bipolar outflow
Frayer D T, University of Toronto	CO and C I line and dust continuum observations of a $z = 2.7$ protogalaxy
Giannakopoulou J, McMaster Univ.	Clues to the formation of giant H II regions: The molecular gas content of one normal and two giant H II regions in M101
Gray M D, University of Bristol	A high frequency maser survey of long period variables
Hasegawa T I, Saint Marys University	Density gradient in Barnard 68
Hasegawa T I, Saint Marys University	Observations of ground-state transition of HDO
Ho P T P, Harvard-Smithsonian CfA	High-velocity HCO^+ emission in the NGC 2264 G molecular outflow
Israel F P, University of Leiden	[C I] and higher CO transitions in galaxy centres
Israel F P, University of Leiden	Radial distribution of molecular gas in M33
Israel F P, University of Leiden	CO excitation of dwarf galaxies
Jewitt D, University of Hawaii	Long-term monitoring of CO emission from Comet Hale-Bopp
Kastner J H, Mass. Inst. of Techn.	Physical conditions in gas orbiting young stars
MacLeod J M, HIA, Canada	Identification of the CH_3OH enhancement mechanisms in bipolar outflows
Matthews H E, JAC, Hawaii	The evolution of the coma of comet Hale-Bopp
Myers P C, Harvard-Smithsonian CfA	Submillimetre continuum from the unusual starless core L1544
Naylor D A, University of Lethbridge	Search for tropospheric CO absorption in Neptune
Owen T, University of Hawaii	The stratospheres of Titan, Neptune and Uranus
Owen T, University of Hawaii	HCN observations of Comet P/Hale-Bopp
Owen T, University of Hawaii	Post SL9 chemistry of Jupiter's stratosphere
Seaquist E R, University of Toronto	A study of dense molecular gas in M82 from the distribution of HCO^+
Senay M C, University of Hawaii	Observations of CO emission from Comet P/Schwassmann-Wachmann 1
Seta M, University of Tokyo	A line study of the W44 supernova remnant / GMC interaction
Stark R, IAP, Paris	The gas-dust connection in protoplanetary discs
Stevens J A, JAC, Hawaii	Bimodal magnetic field distribution in the cores of BL Lacertae objects?
Taylor C L, McMaster University	Cold dust emission in starbursting dwarf galaxies
Vallée J P, HIA, Canada	Extreme infrared (EIR) polarimetry of elongated molecular clouds

van Dishoeck E F, University of Leiden	Physical and chemical evolution of star-forming regions
Ward-Thompson D, ROE, UK	Protostellar collapse
Waters L B F M, Univ. of Amsterdam	A CO survey of ISO-selected AGB and post-AGB stars
Waters L B F M, Univ. of Amsterdam	Millimetre variability of Be stars
Wesselius P R, University of Groningen	[C I] in L183
Wilson C D, McMaster University	Probing the interstellar medium in normal and starburst galaxies

Semester 96B (1st August 1996 — 28th February 1997) — Heterodyne Allocations

Carpenter J, University of Hawaii	An unbiased survey for massive dense cores
Chandler C J, MRAO, UK	Temperature effects in the classification of low-mass protostars
Clancy R T, Space Telescope Institute	Mars & Earth atmospheric studies
Clark T A, University of Calgary	Limb distribution and mapping of the n=19-20 emission on the Sun
Davies J K, JAC, Hawaii	Chemical monitoring of comet Hale-Bopp
Davis G R, University of Saskatchewan	Brightness temperature spectrum of Jupiter
Dent W R F, JAC, Hawaii	A search for HCN in pre-planetary systems
Giannakopoulou J, University of Waterloo	Clues to the formation of giant H II regions: The gas content in M101
Gibb A G, University of Kent	Small-scale structure & evolution of the HH24-26 molecular cloud core
Gray M D, University of Bristol	SiO J = 7-6 masers in R Aqr: Testing the ‘clump’ model for maser emission
Greaves J S, JAC, Hawaii	Are dust grains aligned by ion-neutral drift?
Guilloteau S, IRAM, France	Spectroscopy of T Tauri disks: the physical properties of disks
Hasegawa T I, Saint Marys University	Observations of non-dissociative shocks in molecular clouds
Hasegawa T I, Saint Marys University	Photochemistry in small clouds
Hatchell J, UMIST, UK	Temperature structure of protostellar outflows
Hoare M G, University of Leeds	Dust tori in relation to the ionised winds in luminousYSO’s
Hogerheijde M, University of Leiden	Probing the envelopes of YSO’s in Taurus & Serpens:
Israel F P, University of Leiden	[C I] and CO in galaxy centres
Israel F P, University of Leiden	CO excitation of dwarf galaxies
Israel F P, University of Leiden	Radial distribution of molecular gas in M 33
Israel F P, University of Leiden	Excitation of cold CO in big bulge galaxies
Jackson J M, Boston University	Low metallicity photodissociation regions: IC 10
Jewell P R, JAC, Hawaii	The size & excitation of the Alpha Ori CO envelope
Jewitt D, University of Hawaii	Monitoring of CO emission from Hale-Bopp
Matthews H E, JAC, Hawaii	Interstellar & cometary ices: in Hale-Bopp
Matthews H E, JAC, Hawaii	The evolution of the coma of comet Hale-Bopp
McCutcheon W H, Univ. of British Columbia	Excitation conditions in NGC 6334
Moriarty-Schieven G, JAC, Hawaii	Evolution of accretion disks of embedded young stellar objects
Naylor D A, University of Lethbridge	Search for tropospheric CO absorption in Neptune
Owen T, University of Hawaii	Neptune, Titan & Hale-Bopp
Papadopoulous P, University of Toronto	Temperature, density gradients of the molecular gas in Seyferts
Richer J S, MRAO, UK	Excitation & energetics of molecular clouds: Testing outflow models
van der Werf P, University of Leiden	Confirmation of high-z [C II] 158 micron absorption
van Dishoeck E F, University of Leiden	Physical and chemical evolution of star-forming regions
Ward-Thompson D, ROE, UK	The growth of protostellar accretion disks
Ward-Thompson D, ROE, UK	Pre-stellar cores and the initial conditions for star-formation
Wesselius P R, University of Groningen	[C I] in the ISM
Williams D A, Univ. College London, UK	Direct test of chemical desorption from dust in molecular clouds
Wilson C D, McMaster University	The disk properties of high luminosity class 0 protostars
Wilson C D, McMaster University	Warm gas & dust in the cores of ultraluminous infrared galaxies
Zuckerman B, UCLA	Molecules in protoplanetary disks

Semester 96B (1st August 1996 — 28th February 1997) — SCUBA Allocations

Alton P B, University of Wales, Cardiff	Dust outflows along the minor axis of starburst galaxies
Avery L W, JAC, Hawaii	Shock-modified dust grains in compact outflows
Barthel P D, University of Groningen	The radio to infrared spectral transition in 3CR quasars
Blain A W, MRAO, UK	Submillimetre observations of a hyperluminous star-forming galaxy
Blain A W, MRAO, UK	Observatons of the spectcular cluster 0024+1654
Bourke T L, Harvard-Smithsonian CfA	Submillimetre mapping of the compact H II region S88B
Bridges T J, RGO, UK	The dust distribution in the cooling flow galaxy, NGC 1275
Carpenter J, University of Hawaii	Submillimeter continuum observations of clumps in Orion
Chandler C J, MRAO, UK	Tests of star formation - the density structure of protostellar envelopes
Cimatti A, Observatory of Arcetri, Italy	The nature of high z red galaxies: old or dusty?
Clements D L, ESO, Garching	Are high redshift LIBALs ultraluminous?
Dent W R F, JAC, Hawaii	The heating of dust by outflows
Dent W R F, JAC, Hawaii	Variations in the dust characteristics across circumstellar disks
Dey A, Kitt Peak Nat, Obs., Tucson	Observations of the reddest objects in the Universe
Dominik C, University of Leiden	Submillimeter fluxes of Vega-type stars and candidates
Doyle J G, Armagh Observatory	The nature of the far infrared excess emission in evolved C- and O-rich stars
Dunlop J S, University of Edinburgh	Probing elliptical galaxy evolution of high-redshift radio galaxies
Eales S A, University of Cardiff	A pilot project for a UK-Canada survey of high-redshift galaxies
Eales S A, University of Cardiff	The submillimetre luminosity function and dust formation of galaxies
Fabian A C, University of Cambridge	Self-absorbed emission from hot ion tori: nearby dead quasars
Fich M, University of Waterloo	The central source of the bipolar molecular outflow NGC2264G
Fich M, University of Waterloo & Welch G A, Saint Marys University	First survey for dust clouds in elliptical galaxies
Frayer D T, University of Toronto	Defining the dust content of QSOs, radio & IRAS galaxies at high redshift
Fuller G A, UMIST, UK	A search for embedded binary protostar systems
Gear W K, JAC, Hawaii	A search for compact flat-spectrum cores in steep-spectrum sources
Gear W K, JAC, Hawaii	Are X-ray selected BL Lacs different objects from radio-selected ones?
Giannakopoulou J, University of Waterloo	Hot dust near giant H II regions in M101
Gibb A G, University of Kent	Determining the mass and status of protostellar clumps in L1630
Greaves J S, JAC, Hawaii	Dust formation in detached circumstellar shells
Greene T, University of Hawaii	Investigation of circumstellar envelopes around YSOs in NGC1333
Greene T, University of Hawaii	Physical properties of dust in cold dense cores
Hajjar R, University of Montréal	Dust properties and distribution of some YSOs
Hasegawa T I, Saint Marys University	Far-infrared continuum observations of Barnard 1
Hatchell J, UMIST, UK	Hot dust in high-mass star formation regions
Hogerheijde M R, University of Leiden	Dust emision in the envelopes of embedded, low-mass YSOs in Taurus
Holland W S, JAC, Hawaii	Continuum mapping of proto-brown dwarfs
Holland W S, JAC, Hawaii	The 'Vega phenomenon' around nearby stars
Holland W S, JAC, Hawaii	A search for proto-planetary disks around pulsars
Huard T L, Vanderbilt University	Cold IRAS sources associated with Bok globules: A submillimeter survey
Hughes D H, University of Edinburgh	Emission mechanism dominating the FIR luminosity in radio-quiet quasars
Isaak K G, FCRAO	Dust and gas masses in infrared luminous galaxies
Ishida C M, University of Hawaii	Determination of the submm s.e.d. & the distr. of dust and luminosity in a complete sample of luminous IR galaxies
Israel F P, University of Leiden	FIR continuum of dwarf galaxies
Israel F P, University of Leiden	FIR continuum of extragalactic H II regions
Israel F P, University of Leiden	Submillimeter mapping of the circumstellar disk of Centaurus A
Israel F P, University of Leiden	Cool dust in nearby galaxies
Ivison R J, ROE, UK	Follow-up observations of dusty radio galaxies at high redshift
Ivison R J, ROE, UK	Continuum observations of symbiotic stars: testing the standard models
Jackson J M, Boston University	Cool dust in a metal-poor environment
Jaffe W J, University of Leiden	Nuclear disks in E/S0 galaxies
Jaffe W J, University of Leiden	Sub-mm dust emission from central galaxies in cooling flow clusters

Jewitt D, University of Hawaii	Rotational lightcurve of Pluto
Jewitt D, University of Hawaii	Dusty main-sequence stars
Jura M, UCLA	A protoplanet in the red rectangle?
Jura M, UCLA	A long-lived dust disk around RAFGL 3068?
Kneller T D, University of Alberta	Search for possible class 0 sources driving four molecular outflows
Kwok S, University of Calgary	Submm observations of proto-planetary nebulae with 21 micron features
Launhardt R, Max-Planck, Jena	Protostellar cores in Bok globules
Lehnert M D, University of Leiden	The cold dust distributions of bright IR-selected starburst galaxies
Macdonald G H, University of Kent	The dust environment of hot molecular cores
Mathieu R D, University of Wisconsin	A deep photometric search for disks in pre-main-sequence binaries
Mathieu R D, University of Wisconsin	Sensitive imaging of submmemission from the GG Tau multiple system
Matthews H E, JAC, Hawaii	Dust in an evaporating globule in a Galactic chimney
Matthews H E, JAC, Hawaii	Thermal dust emission from Centaurus A
McCutcheon W H, Univ. of British Columbia	Luminosities, temperatures and structures of IRAS pre-main sequence objects and their environs
McHardy I M, University of Southampton	Shocked jet models for blazars: coordinated monitoring of 3C279
Minchin N R, QMW, UK	Mapping the 450 & 800 micron dust emission from S140
Mitchell G F, Saint Marys University	Changing grain properties through a PDR
Molster F J, University of Amsterdam	Submillimeter imaging of post-AGB stars
Moriarty-Schieven G H, JAC, Hawaii	Density distributions of starless cores in Taurus
Moriarty-Schieven G H, JAC Hawaii	Mm/sub-mm properties of proplyds
Motte F, CEA, Saclay, France	Dust properties of starless clumps & protostellar envelopes in Rho Oph
Penny A J, RAL, UK	A search for dust in globular clusters
Petitpas G, McMaster University	Dust temperature and gas-to-dust ratio of molecular clouds in IC10
Pollanen M D, University of Toronto	Pre-protostellar/protostellar dust cores associated with methanol masers
Pottasch S R, University of Groningen	Submillimeter measurements of planetary nebulae
Rawlings J M C, University College London	Density structure of the pre-collapse protostellar core L1498
Redman R O, HIA, Canada	Metal content and heterogeneity of the M-type asteroids
Redman R O, HIA, Canada	Spectra and sampled lightcurves of 3 bright asteroids
Richer J S, MRAO, UK	Evolution of dust grains in protostars and young stellar objects
Richer J S, MRAO, UK	Star formation in Lynds Class 6 clouds: a pilot study
Roche P D, University of Sussex	Probing the conditions in the outer circumstellar envelope of X Persei
Rottgering H J A, University of Leiden	Dust in high redshift radio galaxies
Rottgering H J A, University of Leiden	Dust in candidate proto-galaxies
Rowan-Robinson M, Imperial Coll. London	A search for sub-mm emission from Hubble deep field galaxies
Sandell G, JAC, Hawaii	Dust emissivity in elephant trunks and cometary globules
Sanders D B, University of Hawaii	Submillimeter continuum observations of high-z powerful radio galaxies
Schuster K F S, IRAM, France	Dust to gas ratio in the envelope of T Tau
Seaquist E R, University of Toronto	Cold dust in IRAS galaxies
Seaquist E R, University of Toronto	A search for cold dust in M82 and NGC 253
Smail I, University of Durham	Imaging of giant arcs: a new probe of star formation in distant galaxies
Smith I A, Rice University, Texas	Observations of soft gamma-ray repeaters
Smith K W, IoA, Cambridge	Mapping the structure of binary formaing envelopes: NGC 1333/IRAS 4
Snellen I A G, University of Leiden	The role of dust in gigahertz peaked spectrum radio sources
Stevens J A, JAC, Hawaii	Far-infrared to mm continuum emission from Fanaroff-Riley radio galaxies
Surace J, University of Hawaii	Submm cont. obs. of complete samples of the nearest ultraluminous galaxies, powerful radio galaxies, & optically selected QSOs
Sylvester R J, University College London	Photometry of fainter Vega-like stars
Tafalla M, Harvard-Smithsonian CfA	Submillimetre emission from two kinematic infall candidates
Taylor C L, McMaster University	Observations of cold dust in starbursting dwarf galaxies
Tothill N F H, QMW, UK	Searching for recent triggered star formation in Sharpless 283
Tothill N F H, QMW, UK	The evolution of high-mass star forming regions
Unger S, RAL, UK	Pulsar powered synchrotron nebulae
van Breugel W, U. California, Livermore	Dust in high redshift ultraluminous IRAS galaxies
van den Ancker M E, Univ. of Amsterdam	Continuum mapping of the environment of young stellar objects
van der Hulst J M, University of Groningen	Cold dust in low surface brightness galaxies

Verheijen M A W, Univeristy of Groningen	The dust content of Ursa Major spirals
Volk K, University of Calgary	Sub-millimeter observations of detached dust shells
Volk K, University of Calgary	Sub-millimeter observations of extreme carbon stars
Ward-Thompson D, ROE, UK	The formation and evolution of pre-stellar cores
Waters L B F M, University of groningen	Structure and variability of Be star discs
Weintraub D A, Vanderbilt University	Mapping of T Tauri and HL Tauri: the thermal emission source regions
Welch G A, Saint Marys University	Cool dust in normal, late-type spiral galaxies
Wilson C D, McMaster University	The dust temperature and gas-to-dust ratio in nearby normal galaxies
Wilson C D, McMaster University	The extended envelope structure of class 0 protostars
Withington S, MRAO, UK	The thermal nature of the FIR emission in high redshift QSOs
Wynn-Williams G, University of Hawaii	Mapping of thermal dust in elliptical galaxies
Wynn-Williams G, University of Hawaii	Search for a hidden AGN in the ultraluminous galaxy IRAS08572+3915
Wynn-Williams G, University of Hawaii	Submillimeter map of W3
Zhang C Y, University of Calgary	Circumnebular cool dust shells of compact planetary nebulae
Zhang C Y, University of Calgary	Submillimeter mapping of the bipolar nebula OH 231.8 + 4.2

SCUBA Allocations

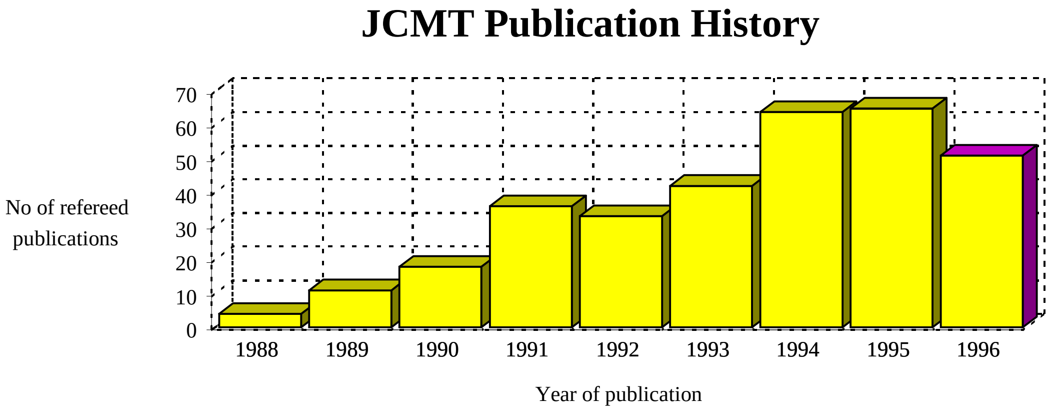
The initial SCUBA observing call limited requests to a maximum of 2 hours of integration time per source. There was also a limit of 24 hours for any application. Due to technical difficulties with the commissioning, none of the above SCUBA allocations were observed during 1996. The entire set of allocations have been carried over into semester 97A and 97B.

Service Observing

During 1996, the partner countries continued to participated in a Service Programme. The UK Service Programme is open to International applications. The total number of shifts given to service observing was 16.25:14:3 for UK:Canada:Netherlands respectively.

Appendix B: List of Publications 1996

This year has not seen the anticipated increase in the number of papers based on JCMT observations. The total of **52** papers published in refereed journal is down from the figures of 64 and 65 for 1994 and 1995 respectively. The drop is probably due to the unreliability of RxA2 during the latter part of 1995. There was also a significant drop in the number of continuum applications and subsequent observers programs since applicants were eagerly awaiting SCUBA. In addition, there were less service applications received.



1996 Publications in refereed journals

Avery, L.W., Chiao, M.: *Enhanced chemical abundances in the L1157 outflow: SiO and CH_3OH observations.*, Astrophys.J., **463**, 642, 1996.

Balcells, M., Sancisi, R.: *Gas accretion in NGC 3656 (Arp 155).*, Astron.J., **111**, 1053, 1996.

Bence, S.J., Richer, J.S., Padman, R.: *RNO 43: a jet-driven super-outflow.*, Mon.Not.R.Astr.Soc., **279**, 866, 1996.

de Boisanger, C., Helmich, F.P. & van Dishoeck, E.F.: *The ionization fraction in dense clouds.*, Astron.Astrophys., **310**, 315, 1996.

Bontemps, S., Ward-Thompson, D. & André, P.: *Discovery of a jet emanating from the protostar HH24 MMS.*, Astron.Astrophys., **314**, 477, 1996.

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Appendix C: Telescope Performance

Weather Statistics

Statistics for both semester 96A and semester 96B are shown in Table C1 while graphical representation of the data is presented in Figure C1.

Month (1996)	Hours available	extended hours used	primary programme lost to weather (hours)	%	backup programme lost to weather (hours)	%
February	440.1	18.9	177.8	40.4	139.3	31.6
March	500.5	36.2	150.9	30.1	150.9	30.1
April	432.0	17.3	24.5	5.7	8.5	2.0
May	472.0	38.8	50.9	10.8	28.9	6.1
June	454.5	8.3	76.1	16.7	76.1	16.7
July	480.0	16.7	53.2	11.1	52.2	10.9
Total	2779.1	136.2	533.4	19.2	455.9	16.4

Month (1996)	Hours available	extended hours used	primary programme lost to weather (hours)	%	backup programme lost to weather (hours)	%
August	406.5	14.3	19.5	4.8	11.5	2.8
September	464.0	28.4	19.4	4.2	18.2	3.9
October	448.0	13.2	73.2	16.3	63.7	14.2
November	456.0	9.5	196.5	43.1	177.0	38.8
December	464.0	6.8	179.0	38.6	178.5	38.5
January	464.0	14.5	134.7	29.0	126.7	27.3
Total	2702.5	86.7	622.3	23.0	575.6	21.3

Table C1: *JCMT weather statistics for semester 96A & semester 96B.*

The importance of having satisfactory backup programmes available is clearly demonstrated from the table. Backup programmes were available for over 90% of the time lost to primary programmes although more than 20% of that time was lost to weather.

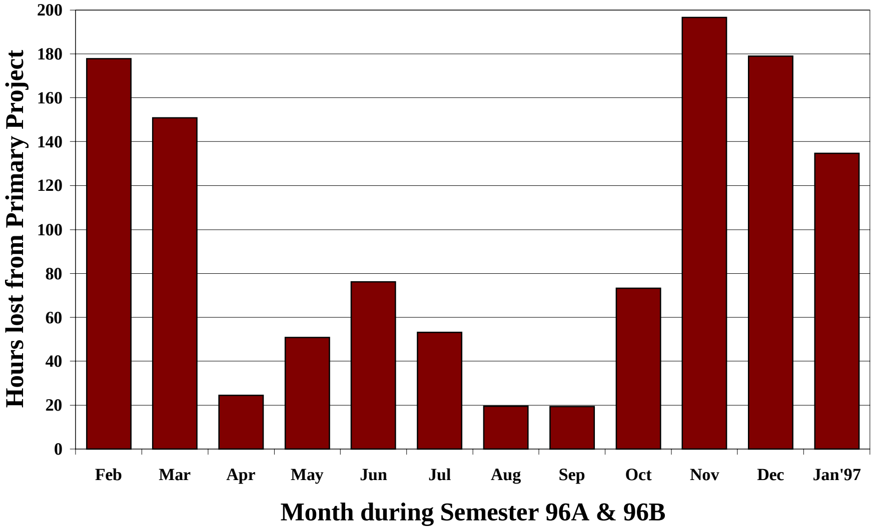

Figure C1: *JCMT weather statistics for semester 96A & semester 96B.*

Fault Statistics

Table C2 displays the faults recorded during 1996 for semesters 96A and 96B. The figures indicate a total of **5.0%** of the time available to primary programmes was lost to faults over the reporting period. At present, use of extended hours and loss to backup programmes are not taken into account but are reported for completeness. Figure C2 shows the number of hours lost through faults for each month.

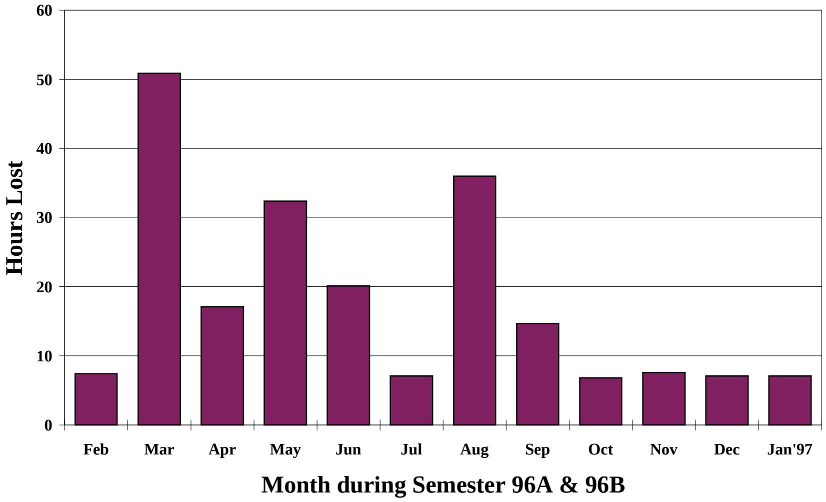

Figure C2: *JCMT fault statistics for semesters 96A & 96B.*

Month (1996)	**Hours available**	**Total**	**ANT**	**INS**	**COMP**	**SOFT**	**CAR**	**OTH**
February	440.1	7.4	2.0	2.9	1.9	0.1	0.5	0.0
March	500.5	50.9	0.0	36.9	0.4	0.0	5.5	8.0
April	432.0	17.1	0.3	12.8	2.7	1.2	0.0	0.1
May	472.0	32.4	6.1	17.0	1.4	1.7	5.8	0.4
June	454.5	20.1	0.6	8.2	1.0	1.4	0.0	9.0
July	480.0	7.1	5.0	1.3	0.0	0.2	0.0	0.6
P(hrs)	2779.1	135.0	14.0	79.1	7.4	4.6	11.8	18.1
B(hrs)		8.8	0.0	8.1	0.5	0.2	0.0	0.0

Month (1996)	**Hours available**	**Total**	**ANT**	**INS**	**COMP**	**SOFT**	**CAR**	**OTH**
August	406.5	36.0	0.2	31.5	1.0	2.0	0.8	0.5
September	464.0	14.7	0.0	9.7	1.5	2.9	0.0	0.6
October	448.0	6.8	0.0	1.4	3.5	0.9	0.0	1.0
November	456.0	7.6	2.1	2.5	2.2	0.2	0.3	0.3
December	464.0	7.1	0.1	0.4	0.8	5.5	0.0	0.3
January	456.0	7.1	0.4	5.3	0.3	0.9	0.0	0.3
P(hrs)	2694.5	79.3	2.8	50.8	9.3	12.4	1.1	3.0
B(hrs)		0.6	0.0	0.3	0.0	0.0	0.3	0.0

Table C2: *JCMT fault statistics for semester 96A & 96B. Wherever possible the faults are categorised into ANT = antenna; INS = instrument; COMP = computer hardware; SOFT = software; CAR = carousel; with the remainder going to OTH = other. P defines the time lost from Primary projects. The category B(hrs) is the time lost to Backup projects.*

Appendix D: Membership of Board and Advisory Panel

JCMT Board as at December 1996

Chairman:

Prof. Dr. H.R. Butcher	Radiosterrewacht Dwingeloo, The Netherlands

Vice Chairman:

Prof. E. Dunford	Central Laboratory for the Research Council, UK

Dr. D.N.B. Hall	University of Hawaii, Honolulu, USA
alt. Prof. G.C. Wynn-Williams	
Prof. R.E. Hills	MRAO, Cambridge, UK
Dr. G.F. Mitchell	Saint Mary's University, Halifax, Canada
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.J.White	Queen Mary & Westfield College, London, UK

Secretary:

Miss R.L. Sirey	PPARC, Swindon, UK

Minute Secretary:

Dr. C. Vincent	PPARC, Swindon, UK

JCMT Advisory Panel as at December 1996

Chairman:

Prof. R.E. Hills	MRAO, Cambridge, UK

Dr. R. Cohen	NRAL, Jodrell Bank, Cheshire, UK
Prof. J. Irwin	Queens University, Kingston, Ontario, Canada
Dr. J.M. MacLeod	HIA, NRC, Victoria, Canada
Dr. J.C.M. Rawlings	University College, London, UK
Dr. D.B. Sanders	University of Hawaii, Honolulu, USA
Dr. R.P. Tilanus	JAC, Hilo, Hawaii
Dr. D. Ward-Thompson	ROE, Edinburgh, UK
Dr. R. Waters	University of Amsterdam, Netherlands

Secretary:

Dr C. Vincent	PPARC, Swindon, UK

Appendix E: JCMT Staff List as at December 1996

Hawaii:

(JAC indicates
shared between
JCMT and
UKIRT)

International
Ian Robson (JCMT, PPARC)

PPARC (JCMT)
Colin Cunningham
Bill Dent
Per Friberg
Walter Gear
Wayne Holland
Tim Jenness
Ken Laidlaw
John Lightfoot
Richard Prestage
Ian Smith
Jason Stevens
Graeme Watt

PPARC (JAC)
Justin Greenhalgh
Derek McCall
Ian Midson
Ian Pain

Netherlands (JCMT)
Fred Baas
Remo Tilanus

Canada (JCMT)
Lorne Avery
Henry Matthews

RCUH (JCMT)
Alan Aindow
Rob Christensen
Iain Coulson
Jeff Cox
Donna DeLorm
Mary Fuka
Alan Hatakeyama
Phil Jewell
William Lundin
John Luthe
Neal Masuda
Cameron Mayer
Gerald Moriarty-Schieven
Firmin Oliveira
Kimberly Pisciotta
Jim Pomeroy
Göran Sandell
John White

RCUH (JAC)
Clayton Ah Hee
Sidney Arakaki
Nigel Atkins
Vernon DeMattos
Marjorie Dougherty
David Fuselier
Mark Horita
Carol Jennings
Nash Kobayashi
Bernadette Leite
Gynna Loper
Richard McCarthy
John Makuakane
Desiree Milar-Okinaka
Roxana Myers
Douglas Reed
Henry Stilmack
Jay Tsutsumi

Royal Observatory Edinburgh:

Rob Ivison (20% JCMT)

Appendix F: Addresses

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Appendix G: Miscellaneous Abbreviations

AAO	Anglo-Australian Observatory, New South Wales, Australia
AGB	Asymptotic Giant Branch (Hertzsprung-Russell diagram)
CADC	Canadian Astronomy Data Centre
CSO	Caltech Submillimeter Observatory, Hawaii, USA
ESO	European Southern Observatory, Garching, Germany
FCRAO	Five College Radio Astronomy Observatory, Mass., USA
GMC	Giant Molecular Cloud
HEMT	High Electron Mobility Transistor
HIA	Herzberg Institute of Astrophysics, Victoria, Canada
IRAM	Instituto de Radioastronomia Milimetrica
IRAS	Infrared Astronomical Satellite
ISO	Infrared Space Observatory (satellite)
IUE	International Ultraviolet Explorer (satellite)
MIT	Massachusetts Inst. of Technology, Cambridge, Mass., USA
MRAO	Mullard Radio Astronomy Observatory, Cambridge, UK
NFRA	Netherlands Foundation for Radio Astronomy, Dwingeloo
QMW	Queen Mary Westfield College, London, UK
QSO	Quasi-Stellar Object
RAL	Rutherford Appleton Laboratory, Chilton, UK
RCUH	Research Corporation of the University of Hawaii
RGO	Royal Greenwich Observatory, Cambridge, UK
ROE	Royal Observatory, Edinburgh, UK
ROSAT	Röntgen x-ray Satellite
SBI	Short Baseline Interferometry
SIS	Superconductor-Insulator-Superconductor (detector)
SMA	Sub-Millimeter Array (Smithsonian Astrophys. Observatory)
SRON	Space Research Organisation Netherlands, Groningen
UCLA	University of California at Los Angeles
UKIRT	United Kingdom Infrared Telescope, Hawaii, USA
UMIST	University of Manchester Institute of Science & Technology
VLBI	Very Long Baseline Interferometry
YSO	Young Stellar Object