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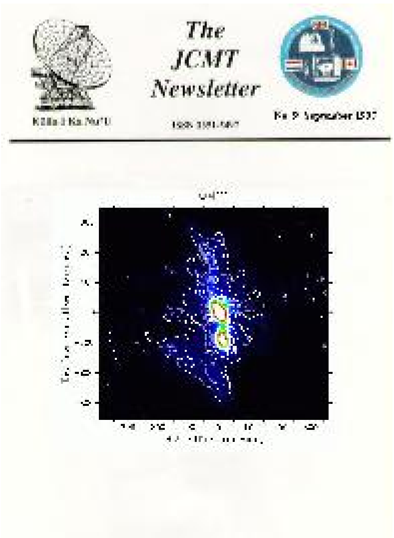


***THE JCMT NEWSLETTER***

**September 1997 Issue Number 9**

**This issue in in electronic format only. There is no paper distribution.**

JCMT Working Schedule for Semester 97B

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# Message from the Director

Text not available at this time.

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# The People Page

**Ed Sison** joined the JAC ETS group as one of the mechanical technicians after working with Murrayair for over 14 years.

**Tamara Brown** has joined us as the Fiscal/Admin Assistant. She enjoys alot of sport activities such as snorkeling, swimming, rollerblading, hiking, and fishing. She is interested in traveling and computers and her hobbies include gardening, sewing and reading.

**Chris Yamasaki** also joined the ETS Group as an Electronics Technician for the JCMT. He has worked as a technician in the medical field for the last 7 years, his former employer being Hilo Medical Center.

**Rob Ivison** is taking two years of his PPARC Advanced Fellowship to work at the JAC where he is doing research work in galaxy formation and evolution.

**Lerothodi Leeuw** from the University of Central Lancashire, England, is expected to be at the JAC for approximately 2.5 years under- taking research in submillimetre properties of AGN (active galactic nuclei). He will be under the direct supervision of Prof. Ian Robson.

The following members of staff have left the JAC recently and we would like to extend our thanks and appreciation to each of them for all their hard work on behalf of the JAC, and wish them every success in the future.

**Walter Gear** and **Jason Stevens** both completed their tours at the JAC and returned to the UK.

**Clayton Ah Hee** terminated his employment at the JAC and has taken a position as Mechanical Technician at GEMINI.

**Cameron Mayor** terminated his employment at the JAC and returned to Canada.

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# Web Access to JCMT Instrumentation Status

The current state of the JCMT instruments, their availability on the telescope and their sensitivities and other observational parameters can always be located on the relevant pages within the JCMT World-Wide Web site:

**RxA2**

**RxB3**

**RxC2**

**SCUBA**

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# Short Baseline Interferometry

It is anticipated that there will be an opportunity to participate in an SBI run around May 1998. The optimum period in which to arrange this 'block' of obsevations has not yet been decided. Further details on the availability of SBI will be found on the JCMT homepage, and via the e-mail exploder, nearer the event.

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

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# RxW

**Progress:**

**for Semester 98A**

The commissioning dates for RxW are provisionally set for late in semester 97B. Unfortunately, the dates will be after the regular PATT deadline and after the ITAC meeting which will be awarding time during semester 98A. It will not be possible to accept applications which specifically require the features and sensitivities of the RxW instrument. Therefore the D-band (690 GHz) section is **NOT** available for semester 98A. C-band observations can be applied for assuming that the project can be completed using the existing RxC2. If, and when, RxW is commissioned, all outstanding C-band applications will be transferred to use the new instrument.



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# SCUBA

The SCUBA homepage has recently been updated concerning latest developments and information regarding applications for semester 98A, see:

August update

Semester 98A Information

SCUBA home page

The SCUBA Interim Polarimeter is scheduled for commissioning in October and should be available for use in semester 98A. Information regarding this device is also given in the Semester 98A Information page.



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# PATT Application Deadline

**Deadlines for receipt of JCMT applications for semester 98A are:**

for UK, Canadian, Netherlands and International applications:

**30th September 1997**

**ALL** applications have the same deadline for this semester.

**Please read the next article - Special Notes for 98A Applicants before filling in your application forms for the forth-coming semester.**

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

**NOTE:** New address for Canadian applications effective immediately.

**Country paying salary of Principal Investigator**

| Canada | Netherlands | UK or International |
|---|---|---|
| Director-General's Office,<br>National Research Council of Canada,<br>5071 West Saanich Road, Victoria, BC,<br>CANADA V8X 4M6 | Dr. J. M. van der Hulst,<br>Kapteyn Astronomical Institute,<br>Postbus 800,<br>NL-9700 AV Groningen,<br>NETHERLANDS | PATT Secretariat,<br>PPARC,<br>Polaris House,<br>Swindon, SN2 1ET,<br>UNITED KINGDOM |

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# Special Notes for 98A Applicants

The deadline for ALL applications for semester 98A (February 1st 1998 through July 31st 1998) is **30th September 1997**. All applications must arrive at their appropriate collection point by September 30th. These will be processed for the ITAC meeting to be held with the other PATT facilities in early December.

The Latex template application form can be downloaded from the JCMT homepage on the Web. An explanation of how to classify applications into UK, Canadian, Netherlands or International, the correct number of copies required, and the correct addresses of the collecting points can also be found on the Web. Electronic submissions will be most welcome in the case of Netherlands and Canadian applications. These electronic applications should be sent to their national collection point. This facility is not yet available for UK. **International applications may be submitted electronically to the JAC beginning with this semester.**. Please read here for further details.

**INSTRUMENTS AVAILABLE**

The current status of RxA2, RxB3, RxC2 and SCUBA can be found on the Web. These instruments will be available throughout the semester.

RxW is scheduled to be commissioned on the telescope in December. This is too late to be able to provide any parameters prior to the ITAC meeting and therefore applications should not request RxW. More specifically, any C-band applications allocated time for RxC2 will automatically be given RxW time should the C-band commissioning proceed successfully. There cannot be any D-band requests for semester 98A.

It is anticipated that there will be an SBI run around May 1998. Applications should be sent in as normal by the appropriate JCMT and CSO deadlines. The instruments available will be only RxA2, RxB3 and RxC2, not RxW.

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# Electronic Submission

**UK** - no scheme has yet been set up to collect UK applications electronically. With the current experiments running on the International applications, it is hoped to include the UK batch within a couple of semesters.

**CN** - HIA, Victoria has the ability to accept electronic submissions. Please refer to local information about formats.

**NL** - these applications are routinely collected electronically at University of Groningen for processing. They are FTP'ed to JAC. Please refer to local information about formats.

**Int** - for the first time the JCMT is experimenting with an electronic system that is a modified version of the HST submission procedures. Please bear with us during this phase. Assuming the system works successfully then we will expand the format to include all applications from all partners, certainly the UK. Fear not, however we experiment, your submissions will not be lost! See below for further details.

# International Electronic Submission

1 - to obtain the most recent JCMT application template, send an email to **jcmtprop@jach.hawaii.edu** with the phrase 'request templates' as the Subject. Following text will be ignored. All neccessary files will be emailed back to you.

2 - complete the Latex template as instructed in the header section. There are only minor modifications to this template from the one that you have already been using. These changes are neccessary because, at some later date, we intend to automatically parse the returned file to generate the tables and files that the TAGs require.

3 - email the completed Latex template back to 'jcmtprop'. You are also required to submit a Postscript version of your application. Each submission will be acknowledged and several people here will be informed of its arrival.

4 - if you do not wish to play with the electronic system, you may still, for this semester, submit your hard copies through the usual route to PATT Secretariat in Swindon, UK.



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# PATT ITAC Report for Semester 97B

### 1. Introduction

This document details the allocations for telescope time made by the ITAC for the semester 97B (1st August 1997 - 31st January 1998).

### 2. Allocations

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

### Applications to be considered

| | |
|---|---|
| UK status | 101 |
| Canadian status# | 46 |
| Netherlands status | 31 |
| International status* | 25 |
| University of Hawaii | 14 |
| TOTAL: | 217 |

# two Canadian long-term carry-overs have not been included in this total.

* this total includes 3 SBI applications through the CSO system.

The PATT meeting was held at the ROE, Edinburgh, UK on 28th & 29th July 1997.

It should be noted that if the PI on an application is a JCMT staff member based in Hilo, then the application is assessed by the appropriate national TAG. However, by Board rule, International status is given to any application where the only named collaborator from any partner country is a JCMT staff member. International applications are assessed by the ITAC members at their meeting.

### Time Available (in 16-hour nights)

| | |
|---|---|
| No. of night set aside in semester 97B | 183.0 |
| Engineering & Commissioning | 33.5 |
| Set aside for SCUBA2! | 30.0 |
| University of Hawaii (10%) | 11.5 |
| Director's discretionary use | 4.0 |
| **Available for PATT science:** | **104.0** |

! this total then concludes the SCUBA 2nd round (SCUBA2) allocations.

The above table indicates the order in which nights are removed from the total available for the semester. Semester 97B covers a winter period from 1st August 1997 through 31st January 1998 inclusive. The JCMT is closed on Christmas Eve.

**Awards (in 16-hour nights)**

| | |
|---|---|
| UK status | 51.625 |
| Canadian status | 23.500 |
| Netherlands status | 18.750 |
| International status | 10.125 |
| University of Hawaii | 11.500 |
| **TOTAL allocation:** | **115.500** |

### 3. Designated Service time

Allocations for this semester are:

CDN = 5.0 shifts allocated;

NL = 0 shifts allocated (but all Netherlands time is flexibly scheduled);

UK = 0 shifts allocated (but several are on the Ukflex listing)..

### 4. Non-standard Instrumentation

There is no non-standard instrumentation scheduled for this semester.

**Instrument distribution**

| | |
|---|---|
| A-band | 15% |
| B-band | 16% |
| C-band | 6% |
| SBI (mainly B-band) | 6% |
| SCUBA | 57% |

### 5. Applications with Long-Term Status

L/M/96A/C08 was given a further 4 night shifts in 97B to complete the comet observations. The student thesis project, M/Y/C05 was also awarded a further 1 shift which should conclude this project.

### 6. Short Baseline Interferometry

After negociation amongst the SBI team it was decided that a session of no longer than 8 days would be possible in early November. The constraints were a combination of the availability of the personnel involved, and the scheduling restrictions on both the CSO and the JCMT. One whole night of setup time was required which left 7 whole nights of observing time to be divided equally between ITAC and CSO applications.

### 7. Use of Daytime Periods

The comet Hale-Bopp remains a daytime object until late September. Then it is observable using morning shifts until early November when it is too far South to be observable with the JCMT. Several daytime shifts have been allocated to the comet watch teams with the same restraints that were imposed during previous semesters (see details in ITAC Report to the previous Board meeting).

## 8. Engineering & Commissioning

Once again the large amount of time set aside for SCUBA 2nd round observing (SCUBA2) and for the commissioning of instrumentation (RxA3i, RxB3 upgrade, SCUBA interim polarimeter and RxW), all other E&C tasks have been kept to a minimum for the semester.

Commissioning of the antenna and instrumentation continues, with periods required a) to characterise and improve the surface via metrology and beam map measures, b) to monitor the antenna performance and tracking through pointing and inclinometry runs, and c) to measure receiver performances and efficiencies.

Time has been allocated for commissioning of RxA3i, RxW and for the SCUBA interim polarimeter according to the commissioning plans made available by the instrument builders. Several shifts have also been left open for upgrading the mixers in RxB3.

## 9. SCUBA 2nd Round (SCUBA2)

A total of 60 shifts were set aside from the allocation for semester 97A for flexibly queue-scheduling SCUBA observations. A total of about 120 shifts of SCUBA2 time had been awarded and therefore the outstanding 60 shifts have been set aside from semester 97B to complete these queues. The SCUBA2 queues will not be carried on beyond the end of semester 97B. All applicants with proposals currently in the SCUBA2 queues have been informed of this procedure.

## 10. Fallback Programmes

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

In addition, there are numerous heterodyne applications set aside to be included as fallback for the SCUBA2. These fallbacks continue to be done in serviced mode by JCMT staff.

## 11. The UKflex System

The UK TAG actually only allocated time to 77.45 shifts of its final allocation of 103.25 shifts. The outstanding 25.8 shifts were designated as UKflex time. A selection of heterodyne A- and B-band applications with high scientific ratings were placed on the UKflex list in priority order and with a nominal time allocation. The intention is that each high-frequency allocation be extended by a shift or two of UKflex time thus increasing the chance of obtaining suitable weather to complete the high-frequency program. Under weather conditions unsuitable for the high-frequency observing, the current observers or staff scientist would undertake observations from the UKflex list in serviced mode. Successful applicants on the UKflex list have been informed that they have to submit complete templates for their observations but that there is no guarantee that any part of their program will be done during the semester.

## 12. Electronic Submission

Various electronic submission procedures have been tried at other PATT facilities with varying degrees of success. Due to the international status, and because there are currently 3 different collection locations for applications to the JCMT, we have so far kept out of these experiments.

The Netherlands already implement a very successful electronic submission scheme. For the current semester 97B round all Netherlands applications were accepted electronically and made available to Hawaii via FTP. The Canadian community is encouraged to submit electronically and, although the numbers are increasing, the majority of applications are still sent as hardcopy.

A system has now been setup in Hawaii that resembles the HST electronic submission procedures. This software suite is under licence from the STScI. For semester 98A, International applicants were encouraged to submit their proposals directly to a designated account at the JAC. If this trial is successful then it will be expanded to include the UK community and also to link to the Canadian and Netherlands schemes. Further details on the electronic submission system is contained in a separate Board paper.

### 13. Procedures for Semester 98A

The deadline for for semester 98A (1st February through 31st July 1998) applications was 30th September 1997 for ALL applicants. This deadline encompasses applications for all available instrumentation on the JCMT (RxA2, RxB3, RxC2, and SCUBA). There is also likely to be an SBI run during the semester. It is not possible to apply for features specific to either RxA3i or to RxW (ie: no D-band observations) since these instruments will not have been commissioned prior to the ITAC meeting in early December. Due to the special nature of the SCUBA interim polarimeter, it may be available for use during semester 98A provided it successfully passes its commissioning tests.



*Last Modification Date 1997/03/12 - Last Modification Author: Graeme Watt (gdw)*

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# Weather and Fault Statistics

The following tables present the weather loss and fault loss for semester 97A. Semester 96B was extended to include February 1997. These tables use the standard February through July statistics for compatibility with earlier tables. A more detailed description of how these tables are created is also available here.

| **Month** | **Avail Hrs** | **Extend Hrs** | **Primary Loss** | **%** | **Backup Loss** | **%** |
|---|---|---|---|---|---|---|
| February | 436.0 | 13.8 | 62.5 | 14.3 | 61.0 | 14.0 |
| March | 496.0 | 20.8 | 196.5 | 39.6 | 184.0 | 37.1 |
| April | 480.0 | 28.3 | 29.2 | 6.1 | 21.2 | 4.4 |
| May | 488.0 | 8.8 | 109.0 | 22.3 | 109.0 | 22.3 |
| June | 477.0 | 13.4 | 122.0 | 25.6 | 108.5 | 22.6 |
| July | 496.0 | 16.0 | 98.3 | 19.8 | 85.8 | 17.3 |
| **Total** | **2873.0** | **101.1** | **617.5** | **21.5** | **569.0** | **19.8** |

**Table 1:** *JCMT weather statistics.*

| **Month** | **Avail** | **Total** | **ANT** | **INS** | **COMP** | **SOFT** | **CAR** | **OTH** |
|---|---|---|---|---|---|---|---|---|
| February | 436.0 | 25.4 | 0.0 | 23.6 | 0.4 | 0.5 | 0.0 | 0.9 |
| March | 496.0 | 20.3 | 0.0 | 18.3 | 0.0 | 0.6 | 1.5 | 0.0 |
| April | 480.0 | 35.4 | 1.9 | 24.7 | 1.8 | 4.9 | 0.0 | 2.2 |
| May | 488.0 | 22.0 | 0.7 | 12.1 | 3.0 | 6.3 | 0.0 | 0.0 |
| June | 477.0 | 24.6 | 0.0 | 12.6 | 1.0 | 5.8 | 1.2 | 4.0 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| July | 496.0 | 15.4 | 0.4 | 8.6 | 2.9 | 1.8 | 0.3 | 1.5 |
| **P(hrs)** | **2873.0** | **143.1** | 3.0 | 99.9 | 9.1 | 19.9 | 3.0 | 8.6 |
| **B(hrs)** | | 0.5 | 0.0 | 0.5 | 0.0 | 0.0 | 0.0 | 0.0 |

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

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# Derivation of Statistical Information

This note provides some explanation on the method of production of the weather and fault statistical summary for the performance of the JCMT. There is very little manual intervention in the generation of these tables, other than to correct obvious errors, mis-labelled categories, or to complete missing entries (where they can be found from other sources).

o The data are extracted from the reports completed by the telescope operators at the end of their shift, one report for each shift (evening or morning); the shifts are normally of 8 hours duration. Because the change-over of TOs does not occur on the shift boundaries, the shift information is handed over to the following operator who will file the report at the end of shift.

o A completely separate fault reporting system is used by the TOs and other staff to record time lost to faults (including problems which have zero-time lost). This system is used by the staff to identify, trouble-shoot and solve the faults. Each fault should then have an appropriate solve report attached for future reference. This system is not used for generating statistics.

o Input from the TO reports comprises

- - the actual time scheduled (normally 8 hours);
- - any extension of this (normally due to good weather and lack of pressing daywork);
- - loss of time on primary and backup programs due to the weather.;

  (**NB** : in flexible observing mode, the move from a high-frequency primary program to a low-frequency primary program because of a deterioration of the weather conditions does not result in any entry in the 'loss to the primary program' category.

- - loss of time to primary and backup programs due to faults, divided into 6 categories : ANTenna, CARousel, INStruments, COMputer, SOFtware, and OTHer. These categorizations are performed by the TO at the time of filing and persist in the analysis, although suggested changes in categories are suggested by the notes to the analysis.

  (**NB** : faults are defined as being in respect of subsystems that have been commissioned are therefore expected to work flawlessly. If the instrument under commissioning has a fault, this is not recorded in the log.

  (**NB** : previous correlations between faults as reported in these TO reports and via the separate fault reporting system show high levels of completeness. A similar correlation is also found between the TO reports and any completed Observer Reports for the period.

- - automated retrieval of weather conditions for the shift in question. These are not analysed further and are not further correlated with the reported conditions.

o Electronic submission of each report automatically triggers the summary analysis program (AUTO_STATS) for the month and semester to date, and the statistics reported to the JCMT Board and in the Annual Report are essentially these results.

o The analysis performed by AUTO_STATS may be repeated following identification and correction of spurious entries, or significant errors in categorization.

o Occasionally reports are not filed on time, and missing reports can seldom be reconstructed.

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# The UKService Program

All administrative duties associated with UKServ have now migrated to the JAC and are under the control of Iain Coulson. UK applications should now be sent to **jcmtserv@jach.hawaii.edu**.

All other enquires should be directed to Iain (imc@jach.hawaii.edu).

Further information and a blank template may be found on the UKService webpage.

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*Graeme Watt (gdw)*

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# High Mass-Loss Carbon Stars and the Evolving Interstellar Medium

We have recently completed a survey of carbon stars using the JCMT. These are evolved, intermediate mass stars which are ejecting large amounts of circumstellar gas and dust, and can readily be observed in CO lines. Carbon stars are the single most important source of carbon returned to the interstellar medium.

The aim of the survey was to measure the relative amounts of the isotopes 12C and 13C in the stellar envelopes, and see how these ejecta will affect the isotopic ratio in surrounding gas clouds. It has always been puzzling that the 12C/13C ratio of the Sun is 89, but that in local clouds is only about 60-70; evolution due to stellar input is an obvious answer, but it has not been quantitatively measured.

In May 1995 we observed the 12CO and 13CO J=2-1 lines of all the accessible high mass-loss carbon stars within about 1 kpc of the Sun. The sample of 10 stars (with individual mass-loss rates greater than 10(-5) M(solar) per year) provides about 80 % of the carbon-rich mass-return within this distance, and should be complete except for very southern sources (below -33 degrees Declination). Examples of the spectra are shown in the figure. The top plot shows spectra of CRL3068, which has one of the highest mass-loss rates, and consequently moderately optically thick emission (tau = 5 for CO J=2-1). The bottom plot shows the spectra of IRC+00365, which has average mass-loss for the sample, but an unusually fast wind (37 km s-1). This source had very weak 13CO emission, of only 13 mK, and the spectrum took 35 minutes of integration to detect.

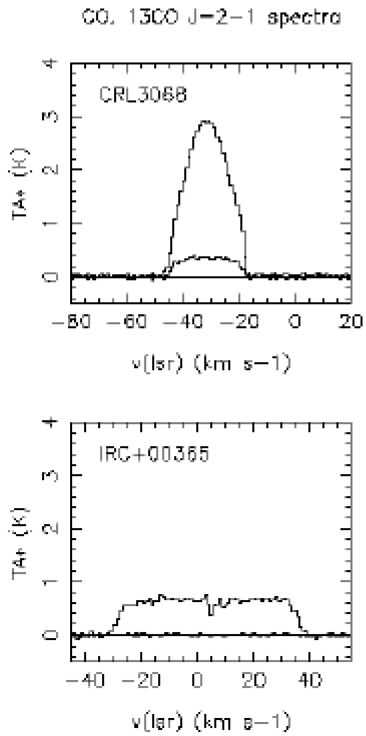


**Figure 1:** *Spectra of CRL3068 and IRC+00365. The 12CO and 13CO J=2-1 spectra are shown by light and heavy lines respectively. The same scales are used, to show the differences in intensity and wind speed (total velocity range of the emission = 2 v(wind)).*

The line intensities were modelled using a radiative transfer code, based on large velocity gradients within the expanding envelope. The 12CO/13CO abundance range for the stellar sample was found to be 25 +/- 13, much more 13C-rich than the solar value of 89. The total rate of ejection into the ISM is 1.5 x 10(-10) M(solar) per year, per square pc of the Galactic plane, and this means the time to totally replace all the gas mass already present would be 9 x 10(10) years. The process is speeded up by the ejecta from O-rich stars, which supply an equal amount of mass-loss (but with 2-5 times lower carbon abundances). The net result is that, since the Sun formed, 4.6 x 10(9) years ago, the ISM has become considerably richer in 13C. Based on our data, the 12C/13C ratio should have decreased from 89 to about 72 (+/- 8). Since the measured ISM ratios are about 60-70, this shows that carbon (and oxygen) stars can in fact explain the isotopic evolution of the gas.

In future observations, we hope to examine the isotopic differences between carbon stars and oxygen stars, plus perhaps cool Wolf-Rayet stars. These data provide a picture of the different nucleosynthesis processes going on, as a function of initial stellar mass, and may explain why intermediate mass stars diverge into the O-rich and C-rich paths.

*Jane Greaves & Wayne Holland*

*(JAC)*

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*Graeme Watt (gdw)*

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# A New Window on Galaxy Formation and Evolution

Surveys of the local Universe have shown that a third of the total bolometric luminosity is emitted at sub-mm and far-infrared wavelengths as a result of reprocessing of star-light by dust (Soifer & Neugebauer 1991). Moreover, some of the most vigorously star-forming galaxies in the local Universe are also those in which the effects of dust obscuration are most significant. While there have been striking advances in the identification of `normal' galaxies at high redshift (z = 2 - 4) using Lyman-dropout techniques (Steidel et al. 1996), such approaches are insensitive to highly obscured star-forming galaxies at these epochs. The presence of at least modest amounts of dust in distant proto-galaxies, especially forming spheroids, is expected given the highly metal-enriched ISM which must be present during their formation (e.g. Mazzei & de Zotti 1996). Thus direct observational evidence of the effect of dust in distant galaxies is urgently required to interpret properly observations of these systems.

Sensitive sub-mm observations present the first opportunity to detect dust in normal galaxies at high redshift. At wavelengths around 100 microns, the bulk of the luminosity of normal, star-forming galaxies is reprocessed star-light from dust and so observations in the sub-mm band can provide robust estimates of both the dust mass and total star-formation rate in a galaxy. Furthermore, the negative K-correction at wavelengths longer than 400 microns means that sub-mm observations select star-forming galaxies at z > 1 in an almost distance-independent manner, providing an efficient method for the serendipitous detection of star-forming galaxies at very large redshifts, z < 10 (Blain & Longair 1993). The potential power and sensitivity of sub-mm observations for investigating galaxy evolution has provoked considerable theoretical interest (Blain & Longair 1993, 1996 - BL96; Blain 1996, 1997; Guiderdoni et al. 1997; Franceschini et al. 1997a, 1997b; Eales & Edmunds 1997). Realistic simulations including instrumental sensitivities and the assumed spectral properties of the sub-mm populations indicate that such surveys have the best chance of success at 850 microns with SCUBA (BL96; Franceschini et al. 1997a).

Most published sub-mm studies of distant galaxies have targeted atypical galaxies (e.g. radio loud galaxies, Ivison et al. 1997). We report here the first deep sub-mm survey to probe the nature of normal galaxies at moderate and high redshift, z = 0.5 - 5. In this study we have attempted to maximise the available sample of distant galaxies by concentrating on fields in moderate-redshift clusters. While the dominant spheroidal populations of these clusters are expected to be quiescent in the sub-mm band, the in-fall of field galaxies associated with the growth of the clusters (Smail et al. 1997) means that these fields may contain over-densities of moderate-redshift field galaxies, as compared with `blank' field surveys.

The main attraction of the clusters observed here, however, is that they are strong gravitational lenses, magnifying any sub-mm source lying behind them (Blain 1997). Given the expected steep rise in the sub-mm counts (BL96), this amplification bias could increase the source counts in these fields by a substantial factor (Blain 1997). Thus these two effects are expected to increase the sub-mm counts in cluster fields above those predicted in typical blank fields, and so the counts in these fields provide upper limits to those in blank fields. The gravitational amplification by the cluster lens alone indicates a maximum surface density of < 10 sources per SCUBA field down to 1 mJy at 850 microns (c.f. Blain 1997). Moreover, by targeting those clusters which contain giant arcs, images of distant field galaxies that are magnified by factors of 10 - 20, we can also obtain otherwise unachievable sensitivity (< 0.1 mJy at 850 microns) on the dust properties of a few serendipitously-positioned normal galaxies at high redshift.

We have started a program to map the core regions of moderate redshift clusters in order to probe the sub-mm properties of intermediate and high redshift field galaxies, including the large population of background galaxies amplified by the cluster lenses. The angular scales of the region where highly magnified high-redshift galaxies are likely to be found is well-matched to the SCUBA field-of-view. In the following sections we give details of the observations and their reduction, and discuss the results within the framework of current theoretical models of galaxy formation and evolution. We adopt H_o = 50 km/s/Mpc and q_o = 0.5.

The maps, linearly interpolated onto an astrometric grid using an approximately Nyquist sampling, of 2 and 4 arcsec/pixel at 450 and 850 microns respectively, are presented in Fig. 1. These maps have been smoothed to the instrumental resolution and have had their boundaries apodized for the purposes of display. Even without including a factor to account for the lensing amplification, the data shown in Fig. 1 are the deepest sub-mm maps ever published, and illustrate the cosmetically clean and flat maps achievable with SCUBA in long integrations.

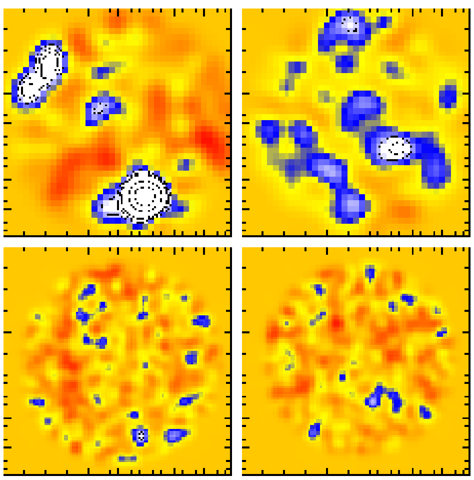

**Fig. 1.** *The 450 and 850 microns maps of the two fields: a) A370, 850 microns; b) Cl2244-02, 850 microns; c) A370, 450 microns; d) Cl2244-02, 450 microns. The maps are smoothed to the instrumental resolution at each wavelength and are displayed as a grayscale from -4 sigma to 4 sigma, the contours are positive and show 3, 4, 5, 10, 15 sigma for each field. The major tick marks are 20 arcsec in all panels.*

Source catalogs from our fields were constructed using the Sextractor package (Bertin & Arnouts 1996). The detection algorithm uses the criterion that the surface brightness in 4 contiguous pixels exceeds a threshold, after subtracting a smooth background signal and convolving the map with a 4 x 4 pixel top-hat filter. Our observations are far from being confusion limited at the current depth (60 beams per source).

First, to assess the contribution of noise to our catalogs we re-ran the detection algorithm on the negative fluctuations in the map. This gives a simple estimate of the number of false-positive detections that may arise from the noise, assuming that the noise properties of the map are Gaussian. We estimate that there are no false detections in our catalogs, and so we conclude that all the detections are real. The presence of the brightest source in the reference beams (60 arcsec to the East and West in the 850 microns map of A370) was disregarded. This detection, however, does confirm the reality of positive features at this faint level, while the absence of any other negative detections limits the number of luminous sources which can lie in the regions covered by the reference beams.

Secondly, to determine the completeness of our sample we added a template faint source to the maps repeatedly, re-ran our detection algorithm and estimated the efficiency of detecting this source as a function of its flux density. This should provide a reliable estimate of the visibility of a faint compact source in the maps. The template source was a scaled version of our calibration source, Uranus. The incompleteness limits are relatively bright for the 450 microns maps because a large proportion of the flux density (about 40%) is found in the low surface brightness wings of the point spread function. The simulations also indicate that the measured 850 microns flux densities are unbiased and are typically accurate to 10% at 25 mJy and 30% at 4 mJy.

We will discuss the detailed properties of the sources in another paper (Ivison, Smail & Blain 1997), where we also place limits on the dust masses of the numerous strongly-lensed distant galaxies covered by our maps. However, we note that, based on their weak or non-detection at 450 microns, all of the 850 microns sources in our sample appear to have the sub-mm spectral characteristics of distant ($z > 1$) star-forming galaxies and are thus unlikely to be associated with the clusters.

Converting the observed number of sources into a surface density and correcting for incompleteness, we determine a cumulative number density across our two fields of 2400 +/- 1000 per square degree down to a 50% completeness limit of 4 mJy at 850 microns (all errors include only Poisson contributions). At 450 microns, the single source we detect places only weak limits on the likely surface density: 1000 +/- 1000 per square degree brighter than 80 mJy. These surface densities should be upper limits to those in a typical blank field because of both a possible excess of star-forming cluster galaxies and also the amplification of background sources by the cluster lens.

We now estimate the likely lens amplification factors, and so place tighter limits on the typical blank-field counts. Because the distances to the detected sources are unknown, this estimate will, by necessity, be crude and so we have not attempted a detailed analysis. The cluster potentials are modelled as isothermal spheres with masses and centers determined from the redshifts and observed shapes of the giant arc in each cluster (Kneib et al. 1993; Smail et al. 1996). In these models the mean amplification factors for background sources ($z > 1$) are about 2 and 1.3 in the regions covered by our maps of A370 and Cl2244-02 respectively, while the observed area of the maps (5.4 square arcmin at 850 microns) corresponds to 1.8 and 4.0 square arcmin in the respective source planes. Correcting the flux densities of our sources to take account of the probable lens amplifications, but not correcting for incompleteness, we predict the source counts presented in Fig. 2. These indicate integrated number densities in blank fields of 2500 +/- 1400 and 3600 +/- 1600 per square degree to flux limits of 4 and 3 mJy respectively at 850 microns.

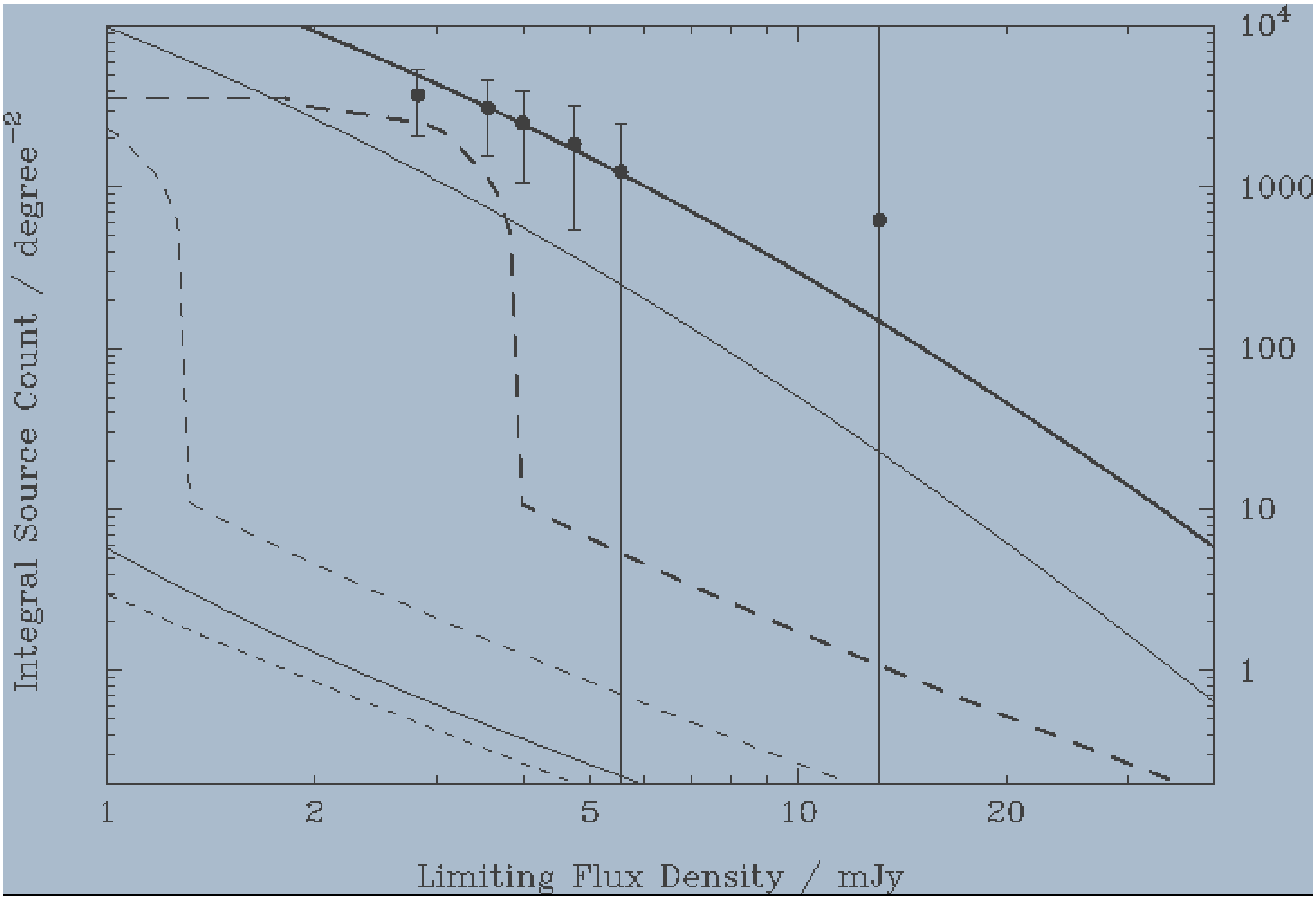


**Fig. 2.** *Models of the integral number counts of sources at 850 microns in a parametric model of galaxy evolution, adapted from BL96 and from a simple model based on the limits on strongly star-forming systems in optical surveys of distant galaxies. The observations are represented by filled circles, with error bars showing the Poisson errors on the integrated counts, note that the errors are not independent on the various points. The observations have been corrected for the effects of lens amplification using simple models for the cluster lenses, but no corrections for incompleteness have been applied. The solid curves represent, in order of increasing predicted counts, models that include: no evolution; (1+z)^3 evolution with z_max = 2 and z_0 = 5 (Model A); and (1+z)^3 evolution with z_max = 2.6 and z_0 = 7 (Model B). The dashed lines represent models where we fill the Universe across z = 0 - 10 with a constant density 0.6E-4 per cubic Mpc) of star-forming galaxies with fixed star-formation rates. In order of increasing predicted counts the dashed lines represent star-formation rates for the population of: M = 20, 50 and 150 M_solar/year, where we have assumed a dust temperature of 60 K. Clearly only models including high densities of strongly star-forming galaxies are compatible with the observed surface density of sources.*

From the flux densities associated with the resolved sources in the fields we calculate lower limits to the background radiation intensities of 2.6E-10 and 2.4E-10 W/m^2/sr at wavelengths of 450 microns and 850 microns respectively, averaged over both fields. By extrapolating the 850 microns counts using our best-fit model (Fig. 2) to faint flux densities, we estimate total intensities of diffuse extragalactic background radiation of about 26E-10 - 28E-10 and 4.4E-10 - 6.7E-10 W/m^2/sr at wavelengths of 450 and 850 microns respectively. These background radiation intensities are broadly consistent with the tentative detection of an isotropic component of the background radiation in the sub-mm by Puget et al. (1996). If we assume that all of the background radiation intensity we infer is due to the formation of massive stars, then we expect that a density parameter of heavy elements of < 6E-4 will have accumulated in the Universe by the present epoch. This density corresponds to about 1.1% of the density parameter in baryons Omega_b if Omega_b = 0.05, and so it is fully consistent with present limits. We reiterate, however, that these are tentative estimates, the accuracy of which depends on the models assumed for both the lens and the form of the counts of distant galaxies.

Due to the negative K-corrections expected for distant galaxies, sub-mm observations provide a good estimate of the volume density of luminous star-forming galaxies at z > 1. In the absence of redshifts for all the sources, the evolution of this population can be understood by comparing parameterised models to the counts (BL96). The BL96 models are based on the 60-micron luminosity function of IRAS galaxies (Saunders et al. 1990) and assume that the luminosities evolve as (1+z)^3 out to a redshift, z_max, and then maintain the enhanced luminosity out to a cutoff redshift, z_0. The form of this evolution is motivated by the observations of similar behaviour in both the radio galaxy and QSO number counts (Dunlop & Peacock 1991) as well as the luminosity density of field galaxies at z < 1 (Lilly et al. 1996). BL96 also give predicted counts for a non-evolving model using the same luminosity function. The adopted parameters for the models described in that paper give source counts which roughly span the range predicted by other similar works (e.g. Guiderdoni et al. 1997). In Fig. 2, we plot both the no-evolution case and two other parametric models based on BL96: model A - Model 2 in BL96 - with values of z_max = 2 and z_0 = 5; and model B, has z_max = 2.6 and z_0 = 7, although most combinations of z_max 2.2 - 2.9 and z_0 > 5 give comparable results.

From Fig. 2 it can be seen that the no evolution predictions fall short by 2 - 3 orders of magnitude of the observations. Thus, this first analysis of a deep sub-mm survey indicates that the number density of strongly star-forming galaxies and hence the mean star-formation rate in the distant Universe is considerably larger than that seen locally. To estimate the extent of this evolution we assume that all the detected sources lie beyond the clusters. We then require strong evolution, of the form given in model B, out to z > 2 to fit the 850 microns counts. For consistency, we check the predictions from model B for the observed counts at 450 microns; 0.7 sources are expected in the two fields, in agreement with the single detection.

We conclude from the 850 microns counts that the integrated star-formation rate in the Universe, as traced by the number density of the most luminous sources, must continue to rise out to z > 2, extending the trend observed at z < 1 (Lilly et al. 1996). The inferred form of evolution corresponds to an increase in the sub-mm luminosity density by a factor of > 10 - 40 at z > 1. At z > 1, the typical luminosity of the star-forming sources we detect is L(FIR) = 0.5E13 - 1.0E13 L_solar, with a star-formation rate of M > 100 - 300 M_solar/yr. Using the observed surface density of these objects and assuming a constant space density of sources between z = 1 - 5, we estimate a number density of strongly star-forming galaxies of: N(M > 150 M_solar/yr) = 1.2E-4 per cubic Mpc, at z > 1.

Limits on the number density of strongly star-forming galaxies at z = 2 - 3.5 have recently been published by Madau et al. (1996) on the basis of Lyman-dropout surveys. Their limit is N(M > 20 M_solar/yr) < 0.6E-4 per cubic Mpc. We plot in Fig. 2 three models using this limit on the number density of sources to uniformly populate the volume from z = 0 - 10, but allowing the corresponding star-formation rate to vary. The star-formation rates used in the three models are: 20, 50 and 150 M_solar/yr, representing the maximum star-formation rate allowed by Madau et al. for this number density, the Madau et al. star-formation limit corrected for dust extinction by the factor of 3 suggested by Pettini et al. (1997) on the basis of the rest-frame UV colors of the distant population, and a mean star-formation rate closer to that needed to fit our observations. From Fig. 2 we see that a galaxy population which complies with the limits from the optical survey of Madau et al. predicts a source density 3 orders of magnitude less than are observed. Even including modest dust extinction proposed by Pettini et al. still under-predicts the observed surface densities (unless the dust in this population is very cold, 40 K, and they have extremely large dust masses). To match the observed surface density of 850 microns sources we must significantly increase the mean star-formation, either by further increasing the star-formation rate associated with the optically-selected samples or more probably by introducing a population of strongly star-forming, but highly obscured, distant galaxies missed by the Lyman-dropout surveys. The number density of these sources is comparable to that of L* ellipticals at the present day if these formed in a short period of time, < 1 Gyr. Moreover, the star-formation rates implied for such a population are similar to the limits we derive. We suggest that the highly obscured, but strongly star-forming population represents the formation phase of luminous elliptical galaxies. Forthcoming deep sub-mm surveys (BL96; Pearson & Rowan-Robinson 1996) are thus necessary to provide the unbiased view of star-formation in the distant Universe needed to understand galaxy formation.

In conclusion then:

We have presented the first sub-mm survey of the distant Universe, deep enough that we should detect the evolving galaxies predicted by current theoretical models, while at the same time covering a sufficiently large area to be statistically reliable. We derive cumulative source counts of 2400 +/- 1000 per square degree down to 4 mJy at 850 microns.

The surface density of faint sources in the sub-mm far exceeds a simple non-evolving model using the locally observed 60-micron galaxy luminosity function. Thus our observations require a substantial increase in the number density of strongly star-forming galaxies at z > 1.

Comparison of our observations with the predictions of simple parametric models indicates that the luminosity density of the brightest sub-mm sources must increase out to at least z = 2. This conclusion appears to contradict the recent claims of a deficit of very strongly star-forming galaxies in optically-selected samples of distant galaxies (Madau et al. 1996). We suggest that such samples may be missing a considerable population of strongly star-forming, dust-obscured galaxies at these epochs.

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*Ian Smail (Durham), Rob Ivison (IfA, Edinburgh), Andrew Blain (MRAO, Cambridge)*

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# JAC Internal Science Seminars

All visiting astronomers are encouraged to give scientific presentations to the JAC staff after their observing run. In addition, many of the JAC staff give presentation on their current research topics.

The seminars are organised by Gerald Moriarty-Schieven.

A list of those given to date and arranged for the future during 1997 can be viewed here

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# Points of Contact

**Joint Astronomy Centre**, 660 North A'ohoku Place, University Park, Hilo, Hawaii 96720, USA

Telephone: +1-808-961 3756

(answerphone) +1-808-935 4332

Fax: +1-808-961 6516

e-mail: **jach.hawaii.edu**

**Mauna Kea**

Hale Pohaku (general): +1-808-935 7606

JCMT Carousel: +1-808-935 0852

Fax in JCMT control room: +1-808-935 5493

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**Newsletter Editor:**

Graeme Watt (at the JAC)

Telephone: +1-808-969-6516

Fax: +1-808-961-6516

(please note the subtle difference in the two numbers above!!)

E-mail: **gdw@jach.hawaii.edu**

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