JCMT SPECTRUM

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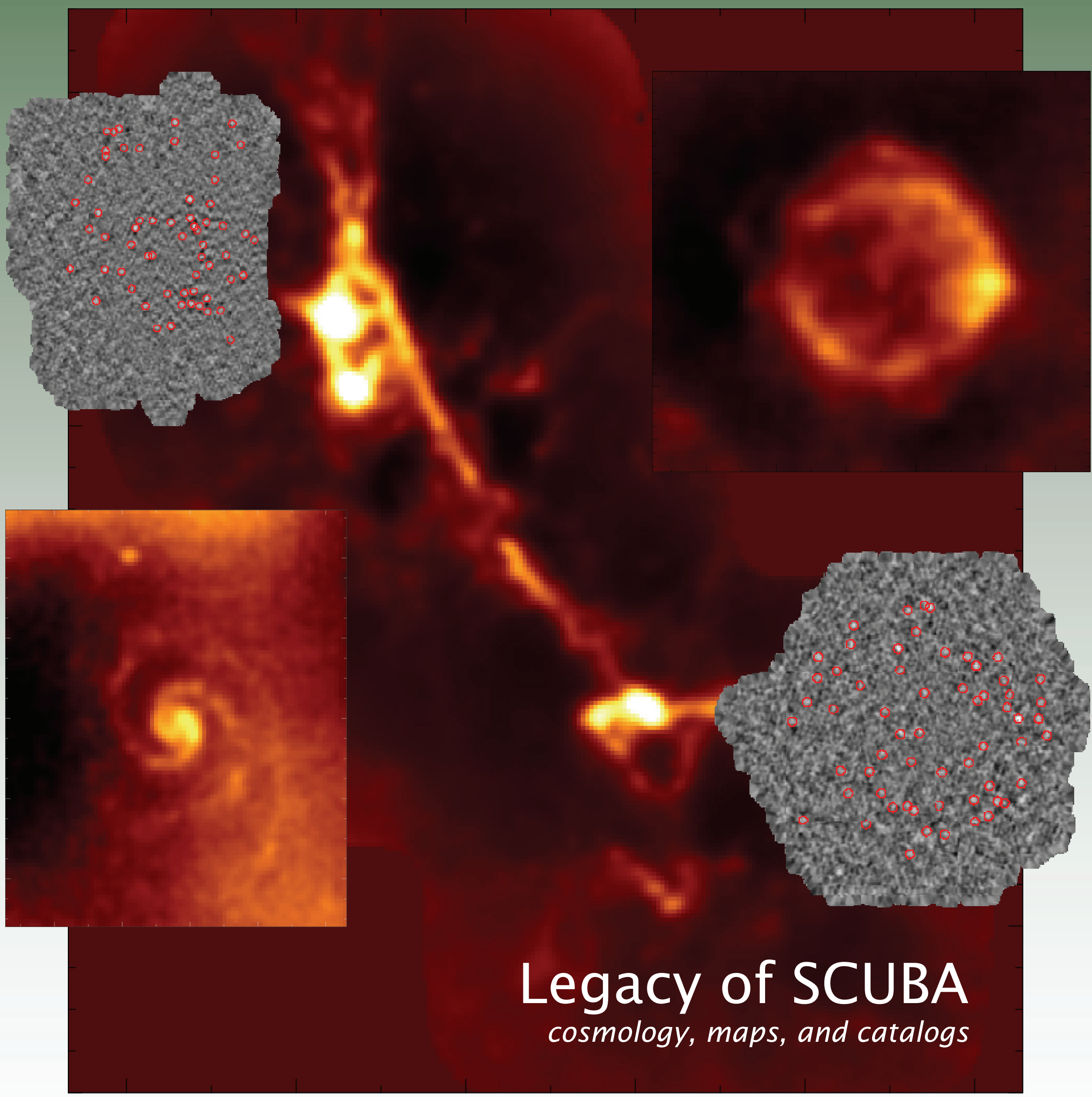

SCUBA Legacy Science Results

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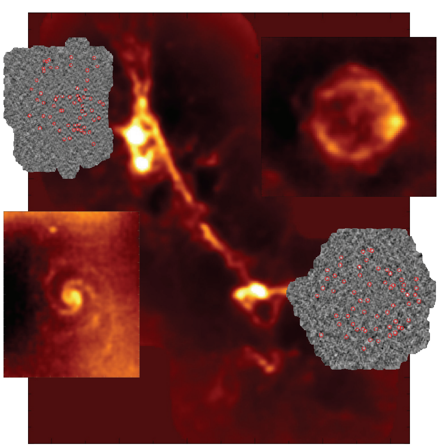
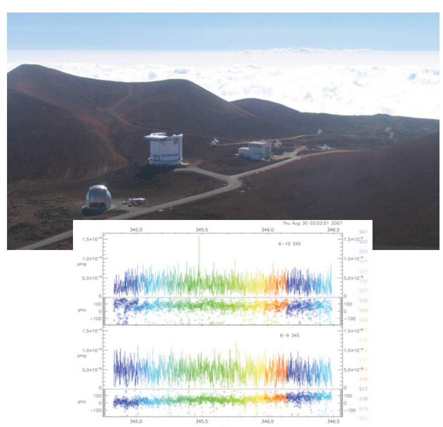


On the front cover: 850 μm SCUBA images of the supernova remnant Cas A (upper right), the Whirlpool Galaxy M 51 (lower left), and the massive star forming region NGC 6334 (center). All of these images (and many more) are available for public download from the CADC web site. SHADES SCUBA 850 μm images of the SXDF (upper left) and Lockman Hole (lower right) fields, indicating the positions of the 120 most secure sources. (Also see Figure 1 and article on page 6 of this issue and Figures 1, 2, and 3, and article on page 8 of this issue.)



On the rear cover: (top) eSMA: JCMT, CSO, & SMA interferometric array. Courtesy Inge Heyer. (bottom) First fringes with the eSMA on baselines between one SMA antenna ("6"), the JCMT ("10"), and the CSO ("9"). The SMA was in its extended configuration yielding eSMA baselines up to ~450 m (baseline 6-9, lower panel), about twice as long as the longest SMA baseline (~225 m). (Also see Figure 1 and article on page 5 of this issue.)

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The Joint Astronomy Centre provides services and support to enable visiting and staff astronomers to undertake top-quality, front-line international-class research using the James Clerk Maxwell Telescope (JCMT) and the United Kingdom Infrared Telescope (UKIRT); to develop these facilities in order to maintain their position as the most advanced of their kind in the world; to operate them in the most cost effective and efficient manner on behalf of the funding agencies; and to be responsive to the changing needs of the contributing organizations.

The JCMT is supported by the United Kingdom's Science and Technology Facilities Council (STFC), the National Research Council Canada (NRC), and the Netherlands Organization for Scientific Research (NWO); it is overseen by the JCMT Board.

The JCMT is a member of the RadioNet consortium.

From the Desk of the Director

Professor Gary Davis (*Director JCMT*) & Antonio Chrysostomou (*Associate Director JCMT*)

Gary Davis, Director JCMT

Welcome to the autumn 2007 edition of *Spectrum*. This edition contains a number of exciting science articles, confirming that the JCMT is a busy place. Certainly all of us who work here know that!

Since the last newsletter, there has been a concerted effort to improve the operational performance of the facility, paying particular attention to the new instruments HARP and ACSIS, the telescope pointing model and the introduction of new (or improved) heterodyne observing modes. Progress on all these aspects has been sure. In parallel the Software and Computing Services have been working hard to improve the computational infrastructure, in particular the communications between the 25 computer systems at the JCMT. This effort has seen our fault rate gradually but surely decrease. At the time of writing, the 6 weeks since the start of the new semester have seen the fault rate remain steady at about 3% of the clear time lost, a significant improvement over where we were 6 months ago.

Science Verification (SV) for the JCMT Legacy Surveys (see the June 2006 issue of *Spectrum*) continues and there have thus far been four phases, each providing valuable feedback to us. The Gould's Belt Survey, Nearby Galaxies Survey and the Spectral Legacy Survey — as the only ones with an interest in HARP data for their surveys — have each sent observers who have really put the telescope and instruments through their paces, giving the whole system a thorough shakedown. These teams should now have sufficient data to begin establishing quality assurance criteria for the summit pipeline. Indications thus far are that the observing modes work well, although bad baselines are currently holding back the teams from starting in earnest. This issue has evolved to top priority for the Instrument Science group but it is not a trivial problem to solve; it is in fact a combination of problems between ACSIS and HARP whose many layers mean that they can only be resolved one at a time.

In the meantime, there has been significant progress in the JCMT Science Archive (JSA). We are regularly shipping data to the CADC and you should all now be accessing your data via their portal. The future development of the project went through a review process this summer. A review panel comprising Dr Sean Carey (IPAC, Chair), Prof. Ian Smail (Durham), Prof. Christine Wilson (McMaster) and Dr Michiel Hogerheijde (Leiden) took a careful look at the Advanced Data Products (ADPs) that the JSA will produce as well as the JSA infrastructure. The Carey Report endorsed the project and its aims, and a finalised document describing the requirements for these ADPs has been made available via the JLS web site (`http://www.jach.hawaii.edu/JCMT/surveys/`). It is now down to the survey teams to consider the algorithms to be used which will calculate these ADPs.

Whilst the transformation of the JCMT's spectroscopic capabilities is now virtually complete, the transformation of the continuum side awaits the arrival of the SCUBA-2 instrument. The project team at the UK ATC have been working very hard throughout the year to bring the instrument to a state of readiness for delivery, and there have been a number of significant technical achievements. At the same time, however, there have been some holdups, as is only to be expected in a project of this complexity. At the time of writing this column, the instrument is scheduled to be shipped to Hawaii in late 2007, with integration and commissioning through the first half of 2008. Modifications to the telescope infrastructure to accommodate the instrument are essentially complete and we are waiting anxiously for this ambitious instrument, with its immense scientific promise, to arrive.

Antonio Chrysostomou, Associate Director JCMT

Whilst HARP/ACSIS and SCUBA-2 are expected to dominate the usage of the telescope for several years, three ancillary instruments are also in various stages of development: ROVER, a polarimeter for use with HARP and RxA; POL-2, a polarimeter being developed at the Université de Montreal for use with SCUBA-2; and FTS-2, a Fourier transform spectrometer being developed at the University of Lethbridge, also for use with SCUBA-2. The ROVER hardware has been delivered and the required software development is underway as time allows amongst our higher-priority commitments. The latter two instruments can only operate in conjunction with SCUBA-2, and are scheduled for delivery in 2008.

A major milestone was recently achieved in our ongoing project to develop an interferometric capability in collaboration with the SMA and the CSO: strong fringes were obtained on all baselines at 345 GHz at the first attempt (see article on page 5). We anticipate issuing a Call for Proposals in late 2007 for a pilot programme consisting of 42 nights spread over several months starting in 2008.

Looking to the future, we reported

(Director's Desk, continued on page 4)

Starlink Software Collection: Puana Release

Brad Cavanagh (*JAC Software Group*)

The Joint Astronomy Centre announces the Puana (Hawaiian for Procyon) release of the Starlink Software Collection. This release includes bug-fixes and feature enhancements throughout the software suite. Improvements that affect JCMT users include improved heterodyne spectrum handling in SPLAT (the spectral line analysis tool), significant data handling improvements in MAKECUBE, and improved cube handling in GAIA.

Conversions between NDF and FITS formats have been improved, including better support for CLASS-style WCS FITS headers.

The ORAC-DR data reduction pipeline now reduces raw ACSIS time-series data. It creates a cube, baselines it, then creates various display files, including integrated intensity maps and channel maps. Development on ORAC-DR for ACSIS is on-going, and future releases will build upon this support.

NDF sectioning can now be done using World Coordinate System coordinates. Using an ACSIS cube as an example, to extract a central portion one would use NDFCOPY:

```
% ndfcopy orion'(5h35m14s~0.5m,-5d22m32s~0.5m,9.312637~10.0)' orion_centre
```

This example extracts a cube with half-arcminute sides centered on the peak emission in the spatial axes and a 10 km/s bandpass centered on 9.313 km/s. A channel map made from this extracted central region is shown in Figure 1.

A new application (but familiar to observers at the JCMT) known as Sourceplot is now bundled. This application plots astronomical objects in azimuth and elevation for any point on Earth.

Download links, release notes, patch information, and mailing list subscription details can be found at `http://starlink.jach.hawaii.edu/`.

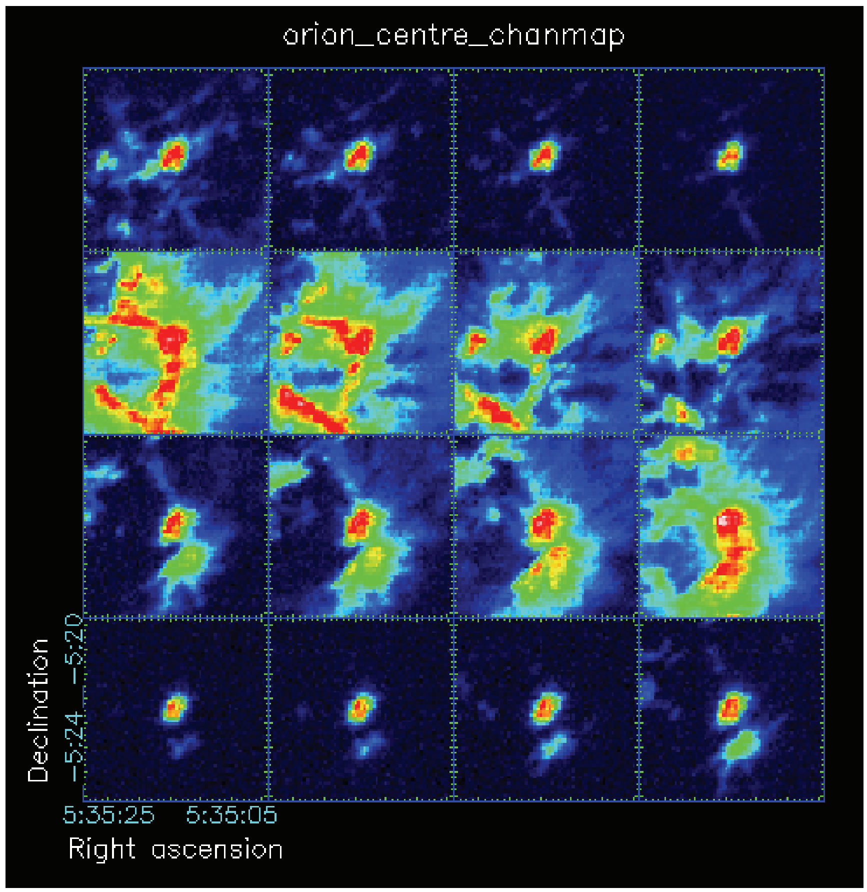

Figure 1. — Channel map of Orion.

(Diretcor's Desk, continued from page 3)

in our previous column that all three agencies had indicated their wish to continue operating the JCMT until at least 2012. This remains the case, and a formal agreement to this effect is in preparation. It is hoped that a final announcement on this issue can be made within the next few months.

Finally, there are some staffing changes to report since the previous Newsletter. Three vacancies have been filled in Engineering and Technical Services with the appointments of Marcel Tognetti as an electronics technician, Ian Campbell as an electronics engineer, and Alan Ryan as a mechanical design engineer. Alan is employed jointly by the JAC and the UH Institute for Astronomy, and his time will be shared between the two organisations. Anubhav Agarwal recently began work at the JAC as a software engineer, and he will be picking up some of the duties previously carried out by Kynan Delorey. Finally, Michele Mulkey joined us in July as Human Resources Manager, filling the post vacated by Ian Midson. Ian returned to the UK this past summer to resume his employment with the Science and Technology Facilities Council (formerly PPARC) after 15 years at the JAC, and we wish him well for the future.

First Light with the eSMA at 345 GHz

Sandrine Bottinelli (*Leiden*) & The eSMA Commissioning Team

Following the successful commissioning of RxWB on the JCMT (*cf.*, *JCMT Spectrum,* Spring 2007) and of Barney on the CSO earlier this year, I am pleased to report that these two receivers were successfully connected to the SMA LO box and that the first fringes at 345 GHz were obtained with the eSMA on the night of August 30th 2007.

The eSMA (extended Sub-mm Array) is a collaboration between the SMA, the JCMT, and the CSO, to join all three observatories into a single interferometric array (see photo on the rear cover). It will operate part-time in the 345 GHz atmospheric window to study Solar System bodies, protoplanetary disks, star forming regions, evolved star envelopes, nearby galaxies, and ultraluminous galaxies at cosmological distances. To be able to carry-out 345 GHz operations, JCMT and CSO receivers must be compatible with SMA receivers, in particular regarding the IF and bandwidth. Hence new 345 GHz receivers have been built for the CSO and the JCMT, namely Barney and RxWB respectively, to meet the required technical specifications set by the SMA receivers.

Daytime testing carried out in early August enabled us to link the new 345 GHz receivers of the single-dish facilities to the LO box of the SMA and a lock was obtained for all receivers. The positive outcome of these tests presaged for a bright future. The critical night was set to August 30th, 2007. The previous eSMA run in May had already set a cornerstone in eSMA commissioning as strong fringes were observed on all baselines at 230 GHz and a high-quality baseline track was obtained. Hence the spirits of the commissioning team [Ken Young (alias "Taco"), Rob Christensen, and Zack Gazak for the SMA, Richard Chamberlin and Hiroshige Yoshida for the CSO, Jim Hoge, Remo Tilanus, and Sandrine Bottinelli for the JCMT] who were present on August 30th were high! They were not disappointed and after carrying out the setup procedure (including recabling the receiver, pointing and focusing), fringes were rapidly acquired on all baselines (as partially shown in Figure 1), despite average, but fortunately stable, weather.

The excitement caused by the strings of dots of Figure 1 is justified by the fact that operating the eSMA at the target frequency of 345 GHz will yield unprecedented spatial resolution and sensitivities at these frequencies, thanks to the added baseline length and collecting areas of the JCMT and the CSO. Hence the eSMA will naturally allow one to obtain unique science observations and achieve novel results in the aforementioned areas. The interested reader will find more information on the potential early science program that was discussed at a workshop organized in Leiden on February 1-2 2007 (see http://www.strw.leidenuniv.nl/esma-workshop/). Moreover, information on the resolution and sensitivity of the eSMA can be obtained by going to the "tools" page of the "SMA observer center" (http://sma1.sma.hawaii.edu/).

Congratulations and many thanks to everyone involved in reaching this achievement!

eSMA developments at the JCMT are financially supported by a Netherlands NWO-M grant awarded to Ewine van Dishoeck (Leiden Observatory/MPE Garching). In the past, the grant provided for the technical expertise and support from Leo de Jong (SRON) and Rob Millenaar (ASTRON), who both came to the JAC for extended visits to assist with the conversion and commissioning of RxWB. Currently, this grant supports S. Bottinelli (Leiden Observatory) to travel to the JAC to participate in the commissioning of the eSMA and calibrate the instrument. We also acknowledge the thesis work of Emily Curtis whose dedicated laboratory work on building and testing parts of RxWB contributed significantly to the successful completion of this receiver and hence of the advancement of the eSMA.

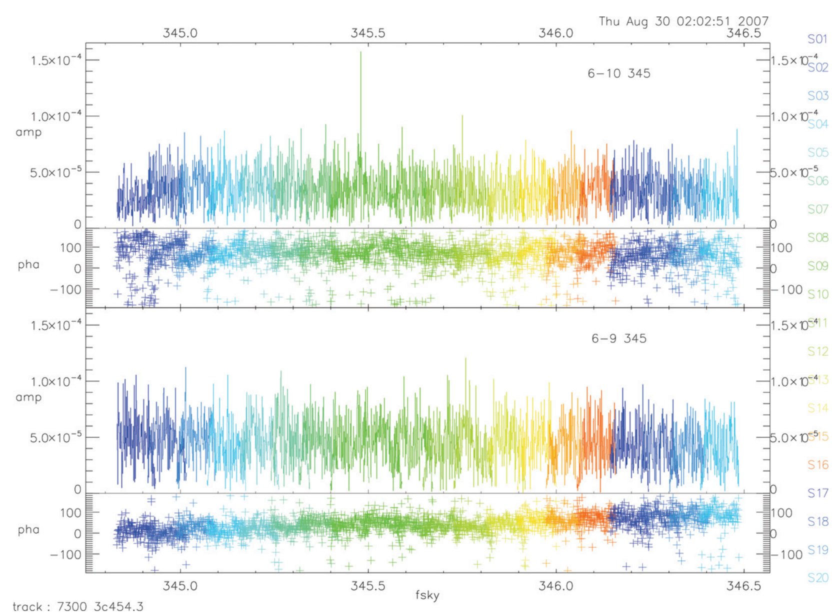

Figure 1. — First fringes with the eSMA on baselines between one SMA antenna ("6"), the JCMT ("10"), and the CSO ("9"). The SMA was in its extended configuration yielding eSMA baselines up to ~450 m (baseline 6-9, lower panel), about twice as long as the longest SMA baseline (~225 m). (Also see rear cover of this issue.)

SHADES: A Cosmological SCUBA Legacy

James Dunlop (*Edinburgh*) & The SHADES Consortium

SHADES, the SCUBA Half Degree Extragalactic Survey, commenced at the JCMT in early 2003 (http://www.roe.ac.uk/ifa/shades/). The original plan was to map a total area of 0.5 deg^2, to an rms noise level of ~2 mJy at 850 μm. The choice of survey depth was designed to play to the strengths of SCUBA on the JCMT — significant numbers of extragalactic sources were known to be detectable at the ~8 mJy level (Scott *et al.* 2002), and yet by staying reasonably bright we aimed to avoid the more severe effects of source confusion resulting from the 14" beam. The planned survey area was then chosen to yield a statistically useful sample of a few hundred sub-mm sources.

SHADES has been undertaken by a large consortium of UK and Canadian astronomers, many of whom had previously worked in competition, undertaking the pioneering sub-mm surveys which followed first-light with SCUBA in 1997 (Smail *et al.* 1997; Hughes *et al.* 1998; Eales *et al.* 2000). SHADES was motivated by many science drivers, in particular the desire to clarify the number density, redshift distribution, and clustering properties of the bright sub-mm selected galaxy population (see van Kampen *et al.* 2005, Mortier *et al.* 2005). However, at a basic level, all involved accepted that, to make further progress in the field, what was now required was a large and complete sample of 850 μm sources (analogous to the 3CR radio source sample, which ultimately revolutionized extragalactic radio astronomy). The problem was that the creation of such a sample with SCUBA required one third of the available time on the JCMT over 3 years.

Since 2003 a large number of astronomers within the SHADES consortium (ably supported by the staff of the JCMT) have worked extremely hard to complete this unique sub-mm survey. The project required that consortium members staff a very large number of flexibly-scheduled nights on Mauna Kea, often with an ailing SCUBA camera. In the end, by the time SCUBA finally died in 2005, we had succeeded in mapping approximately 0.25 deg^2, split between two survey fields. While short of our original goal, the resulting 850 μm maps of the Lockman Hole and SXDF/UDS fields shown in Figure 1 form the largest extragalactic sub-mm imaging survey of meaningful depth ever undertaken, and provide a uniquely powerful resource for the study of the bright sub-mm galaxy population.

As befits such a scarce resource, the SHADES 850 μm data have been subjected to an extremely thorough analysis, with 4 separate sub-groups within the consortium undertaking independent data reduction and source extraction. The final merged results of this exhaustive process, reported in Coppin *et al.* (2006), include a new sample of 120 sub-mm sources with statistically deboosted fluxes, and a definitive

(SHADES, continued on page 7)

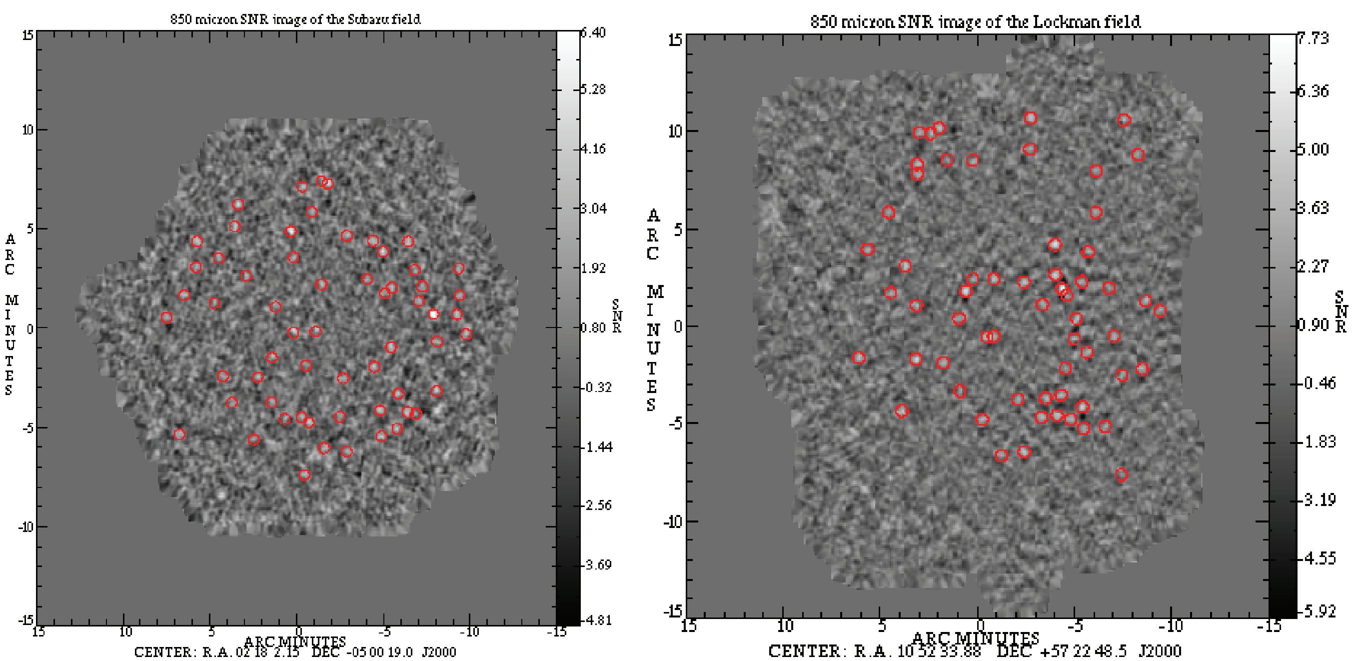

Figure 1. — The SHADES SCUBA 850 μm images of the SXDF (left) and Lockman Hole (right) fields, indicating the positions of the 120 most secure sources. (Also see front cover of this issue.)

(SHADES, continued from page 6)

measurement of the 850 μm source counts in the range 1–10 mJy (Figure 2). These results, and the lessons learned in getting to grips with these data, have played a major role in informing the design of the SCUBA-2 Cosmology Legacy Survey (http://www.jach.hawaii.edu/JCMT/surveys/Cosmology.html).

While some SHADES consortium members worked to build the SCUBA maps, others have made extensive efforts to assembling the extensive supporting multi-frequency dataset required to extract astrophysical results from 4σ peaks in SCUBA maps. In particular, the VLA has been used to assemble extremely deep 1.4 GHz radio images in both the SHADES survey fields. As a result, ~70% of the SHADES sources have now been identified with radio sources, yielding positions accurate to ~1 arcsec (Ivison *et al.* 2007), and a first estimate of the redshift distribution of the SHADES sample has been derived (Figure 3; Aretxaga *et al.* 2007). These results, derived by fitting the radio-submm-farIR fluxes of SHADES galaxies to a range of observed low-redshift template SEDs, will be further refined as additional sub-mm and mm data become available. This process has already commenced, through the SHARC2 350 μm observations reported by Coppin *et al.* (2007), and new 1.1 mm JCMT AzTEC mapping of the SHADES fields (see below).

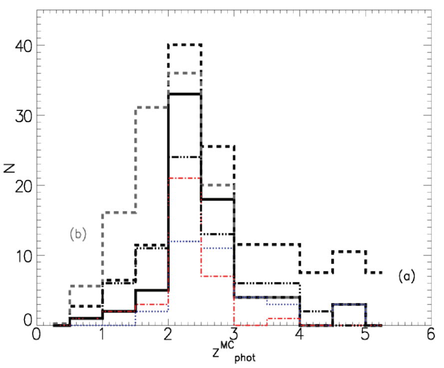

Figure 3. — The first estimate of the redshift distribution of the SHADES galaxies, derived by fitting their observed long-wavelength colours to a range of low-redshift template spectral energy distributions. The results broadly confirm previous evidence that the redshift distribution peaks in the range 2<z<3, albeit still with large uncertainties.

SHADES has also benefited from the advent of the Spitzer Space Telescope. The SXDF field is part of the SWIRE survey (http://swire.ipac.caltech.edu/swire/), while deep IRAC and MIPS imaging of the Lockman Hole has been obtained in collaboration with the Spitzer GTO team led by George Rieke in Arizona. These mid-IR data, coupled with optical and near infrared imaging obtained from Subaru (Furasawa *et al.* 2007) and UKIRT (as part of UKIDSS; http://www.ukidss.org/) have enabled additional source identification, more sophisticated (and independent) redshift estimation, and a detailed exploration of the stellar masses and star-formation histories of the SHADES galaxies (Figure 4; Dye *et al.* 2007; Clements *et al.* 2007). These studies indicate that bright sub-mm sources are generally housed in already massive galaxies (>10^{11} $M_\odot$), with the "current" starburst having been preceded by previous star-formation events which formed at least half of the final stellar mass.

Most recently we have been exploring the results of pushing the effective depth of the SHADES imaging via a variety of stacking analyses (Serjeant *et al.* 2007) and investigating what constraints SHADES can place on the clustering properties of the sub-mm galaxy population (van Kampen *et al.* 2008).

A total of ten SHADES papers have now been published or submitted for publication. Nevertheless, and

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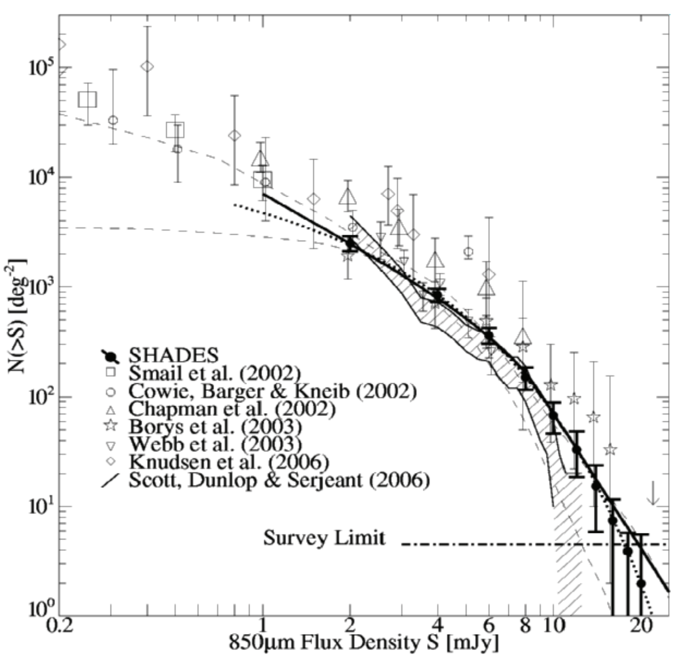

Figure 2. — The 850 μm number counts, as derived from the images shown in Figure 1. The result is the best estimate to date of the number counts in the 1–10 mJy range, and resolution of 20–30% of the background.

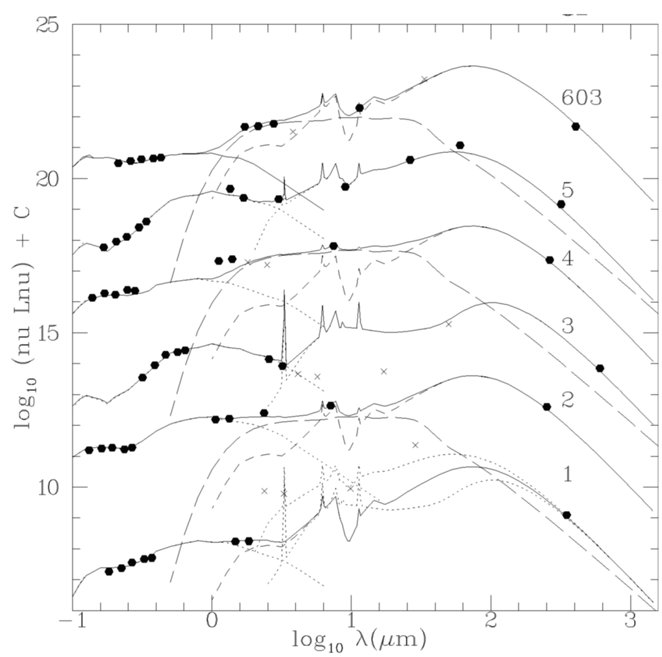

Figure 4. — Examples of SED fitting to the full range of optical+infrared+submm data now available for the SHADES sources, from which redshifts, star-formation histories, and galaxy masses can be estimated.

The SCUBA Legacy Maps and Catalogues

James Di Francesco, Doug Johnstone (*NRC/HIA*), Helen Kirk (*Victoria*),
Todd MacKenzie (*Prince Edward Island*), & Elizabeth Ledwosinska (*McGill*)

SCUBA was the flagship instrument for the JCMT, and for nine years (1996–2005) its combination of high sensitivity and wide area coverage allowed for some of the most stunning results in modern astronomy. SCUBA data have been long available to the public but utilization of these data could be difficult for those not well versed in the SURF reduction package or those who simply didn't have the time to reduce the data themselves.

To allow SCUBA data to be disseminated as widely as possible to the community, we have uniformly re-reduced all viable SCUBA jiggle and scan data at 850 and 450 μm. Where possible, data obtained at several epochs were combined to provide superior map quality. All resulting maps are available for public download from Canadian Astronomical Data Centre (CADC) from the following URL: `http://www.cadc.hia.nrc.gc.ca/community/scubalegacy/`. In this brief report, we describe the results of this effort. Extensive details of the project can be found in a paper located at the website that will be soon published in the Astrophysical Journal Supplement Series (Di Francesco *et al.* 2008, in press).

We downloaded all 35,455 SCUBA data files in the archive that corresponded to 850 or 450 μm data taken in jiggle or scan mode, a total of 78.7 GB. We removed all Solar System objects from the ensemble, given the variations in their sizes, brightnesses and positions, as well as all obvious engineering data, leaving 28,534 files (69.9 GB).

To make useful maps of the calibrated data, we divided the sky into 1.2 deg × 1.2 deg ("square-degree") regions (overlapping with their

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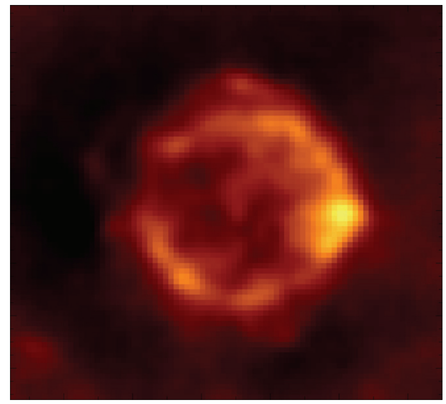

Figure 1. — 850 μm SCUBA image of the supernova remnant Cas A. All of these images are available for public download from the CADC web site. (Also see front cover of this issue.)

(SHADES, continued from page 7)

despite the premature death of SCUBA, there is still much to be done. First, a lot has still to be learned about the 850 μm sources uncovered in the SCUBA map. In particular, less than 10% of these sources have robust spectroscopic redshifts, despite many having been targeted during multi-object spectroscopic campaigns on 8-m class telescopes. This is in part because many of the SHADES galaxies are very red galaxies, and we expect to improve the spectroscopic completeness of the sample via a major new approved programme of deep, red optical FORS2 spectroscopy with the VLT in the SXDF/UDS field (PI Almaini), supplemented in the future by near-infrared spectroscopy with FMOS on Subaru. Improved Spitzer data will also be supplied in early 2008 via a new Spitzer Legacy program in the SXDF/UDS field (PI Dunlop), SMA observations are being used to clarify ambiguous radio identifications, and data anticipated from Herschel in the SHADES fields should revolutionize our knowledge of their SEDs and bolometric luminosities.

Excitingly, this continually improving multi-frequency follow-up will take place within the context of a new JCMT SHADES dataset, which has been provided by the AzTEC camera (PI Grant Wilson — see *JCMT Spectrum*, Spring 2007). This was used on the JCMT in 2005/06 to map the SHADES fields at 1.1 mm. These new SHADES–AzTEC maps have more than covered the original planned total area of 0.5 deg^2. These maps are thus yielding new bright sources, as well as allowing us to obtain 1.1mm flux measurements for many of the 850 μm sources extracted from the original SCUBA maps. A new SHADES-AzTEC consortium has now been formed, and the SHADES AzTEC maps and source lists will be presented in Austermann *et al.* (2007). New stacking analyses, and techniques for joint source extraction are currently being explored.

Over the next 2 years we expect to complete the analysis of the SHADES SCUBA+AzTEC data in the context of the still-growing multi-frequency supporting dataset. The results will include the clearest picture to date of the number density, redshift distribution, and clustering properties of the bright sub-mm/mm galaxy population. These measurements are already providing some of the most demanding observational benchmarks for theoretical models of galaxy formation, as well as helping us to refine the key outstanding questions to be answered by SCUBA–2. (Also see article on page 10.)

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(Legacy, continued from page 8)
neighbours by 0.1 deg). Maps were created from all 850 or 450 μm jiggle or scan data within each respective region using the "matrix inversion" technique of Johnstone et al. (2000). Full details of the data reduction, calibration, map making and image improvement can be found in Di Francesco *et al*. (2008). After calibrating, smoothing, and flattening the images, the absolute flux uncertainties of the maps are ~20% at 850 μm and ~50% at 450 μm.

All maps were visually inspected and those not meeting a qualitative assessment were removed from the Datasets. Unfortunately, maps of the deep "cosmological" fields (*e.g.*, the SHADES field, see article on page 6) were removed since those made with matrix inversion did not have good quality. Those data were obtained with a very specific chopping throw and angle, and the matrix inversion method works best when multiple scales are sampled.

The Fundamental Dataset (containing the best calibration) contains 1423 and 1357 deg^2 maps at 850 and 450 μm respectively with total sky coverages of 19.6 square degrees and 16.4 square degrees respectively. The effective resolutions of the maps are 22.9" FWHM at 850 μm and 17.3" at 450 μm. (An Extended Dataset containing all SCUBA map data regardless of inherent calibration quality is also available for those looking for widest areal coverage.) These resolutions are larger than the diffraction limit of the JCMT because of the convolutions with narrow Gaussians to reduce pixel-to-pixel noise and because of the low-amplitude error beam of ~40" FWHM at both wavelengths.

Figures 1–3 show excellent examples of 850 μm SCUBA maps produced from this effort, including M 51, NGC 6334, and Cassiopeia A. All emission maps are available for download from the CADC web site.

To quantify the emission located in the SCUBA Datasets, we constructed catalogues of objects within the 850 μm maps. Object identification was performed using the two-dimensional "clumpfind" algorithm (Williams, de Geus & Blitz 1994) down to a small multiple of the minimum noise in each map. The resulting identifications form the bases of the Fundamental Map Object Catalogue (FMOC, with 5061 objects) and the Extended Map Object Catalogue (EMOC, with 6118 objects). The Catalogues also list for each object the maximum 850 μm intensity, sizes of each object defined by Clumpfind, and 850 μm fluxes, in addition to the associated 850 μm noise level. Where possible, the Catalogues also list the maximum 450 μm flux and peak flux density and the local 450 μm noise level. Finally, the Catalogues provide where possible a tentative association with previously known objects in the SIMBAD astronomical database.

The Catalogues have been converted to the standard machine-readible format of the Astrophysical Journal and are also available for download from the aforementioned CADC website. Until SCUBA-2 is able to produce data that are orders of magnitude in scale larger than that produced by SCUBA, we hope the SCUBA Legacy Maps and Catalogues will allow a wider use of submillimetre continuum data throughout the astronomical community.

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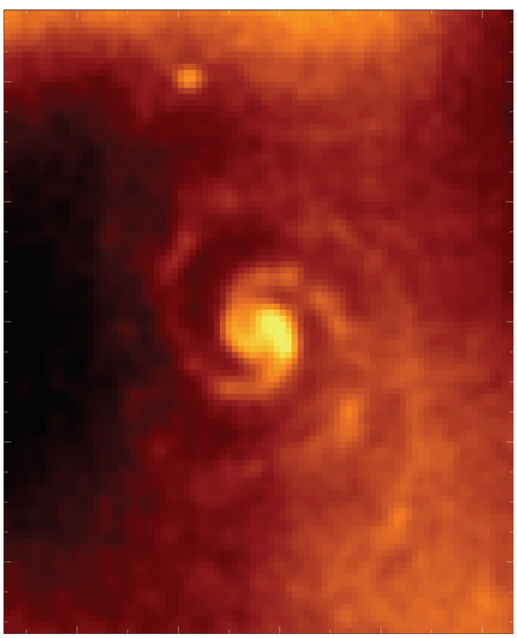

Figure 2. — 850 μm SCUBA image of the Whirlpool Galaxy, M 51. (Also see front cover of this issue.)

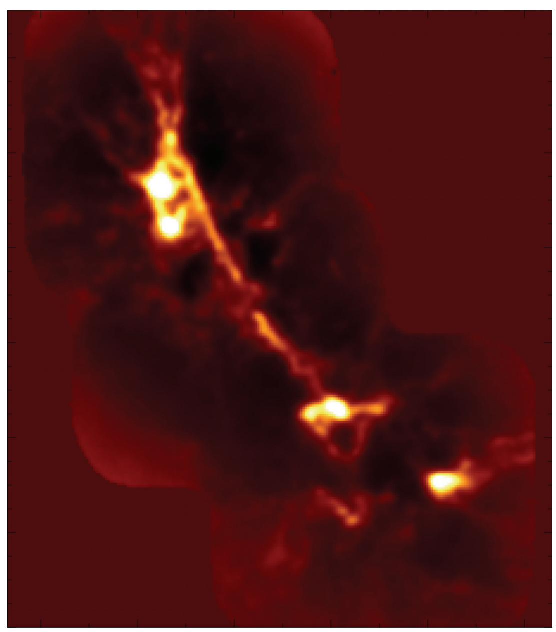

Figure 3. — 850 μm SCUBA image of the massive star forming region NGC 6334. *(Also see front cover of this issue.)*

Extreme Activity in a Biased Environment: An AzTEC 1.1 mm Survey

James Geach (*Durham*) & The JCMT/AzTEC MS 0451-03 Collaboration

Background

The strong decline in the star formation rate of the Universe over the past 8 Gyrs is thought to be in part due to the suppression of star formation within gas-rich late-types as they are accreted into dense environments during the build up of groups and clusters (Tresse *et al.* 2007). The observed paucity of intensely star forming galaxies in rich environments out to *z~1*, and passive populations residing in the cores of clusters seem to support this view (*e.g.*, Dressler *et al.* 1997; Treu *et al.* 2003). What about starburst galaxies that are obscured by dust? Dusty starbursts could be contributing a significant fraction of the total cluster star formation rate, but are likely to be severely underestimated or even missed in magnitude limited optical surveys. Survival of starbursts within clusters could thus be an important stage in the late-development of massive galaxies, and an alternative to the 'dry-merger' scenario of red galaxy formation (*e.g.*, van Dokkum 2005).

To address this issue, we have been undertaking a panoramic, panchromatic survey of the rich cluster MS 0451-03 (*z=0.55*). Our large dataset includes extensive ground based optical/near-IR imaging and spectroscopy, *Spitzer* and *Hubble* imaging. Our goal is to build up an unbiased picture of activity in the cluster — a complete census of star formation. Our survey will benefit significantly from the most recent addition to our dataset: a 1.1 mm map obtained with the AzTEC camera on JCMT (Austermann *et al.* 2006; and see the Spring 2007 issue of *Spectrum*). The millimeter map will be essential to unveil any extremely luminous obscured starbursts within the cluster.

Current work — Identifying Counterparts to SMGs

Our *Spitzer* 24 μm imaging has revealed a population of moderate starburst galaxies residing within this cluster (SFR~50 $M_\odot$/yr, see Geach *et al.* 2006), already hinting that this cluster harbours significant activity which is obscured from optical views (the SFRs derived from the mid-infrared are on average a factor 5 higher than those derived from optical indicators). What of the most extreme tail of this population? We are now searching for submillimetre galaxies (SMGs) in the cluster.

Finding counterparts to SMGs at other wavelengths is extremely challenging, but essential to confirm their identity. The large beam size of AzTEC (FWHM~20") means that any individual detection could contain several potential optical counterparts within a reasonable search radius. Therefore, to help in this search, we have made use of the 24 μm imaging (*e.g.*, Ivison *et al.* 2007), employing a two-stage match: first matching 1.1 mm detections to MIPS 24 μm sources, and then finding the most likely optical counterparts in deep optical images. At the time of

(AzTEC, continued on page 11)

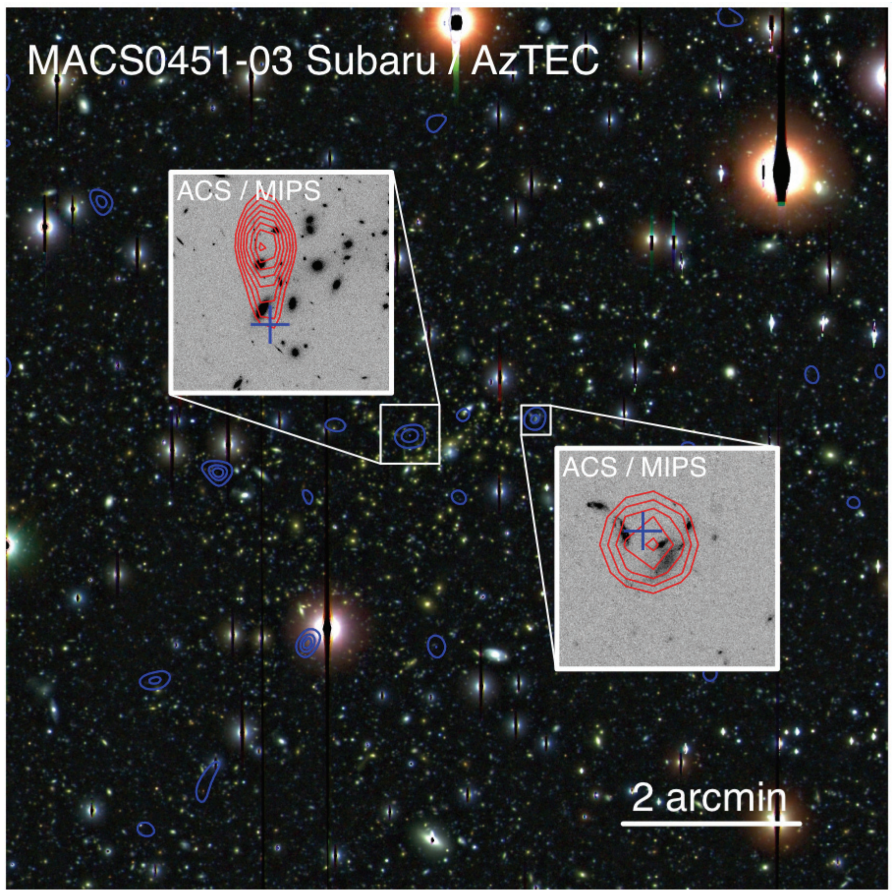

Figure 1. — A 10'×10' true colour (Bri) image of the cluster MS 0451-03 showing potential AzTEC sources as contours. The insets show close-ups of two AzTEC detections: the images are from HST-ACS, with 24 μm SST-MIPS contours overlaid. In each case the AzTEC centroid is indicated with a cross. We have a spectroscopic follow-up program to confirm the identity of counterparts to the SMGs — with the aim of detecting galaxies residing within the cluster at z=0.55.

The Night Shift

Ben Warrington (*JCMT Telescope System Specialist*)

I have been asked to write an article from the TSS point of view for this newsletter. I have the sneaking suspicion that if I acquiesce, they will come back and ask me again for the next newsletter, and the next. Oh well, I suppose I can manage to type a piece every six months.

By now, it is no longer news that the JCMT is going through an extraordinary period of transition. The process started about two years ago with the arrival of ACSIS and, shortly thereafter, HARP. Accompanying these arrivals, of course, was the arrival of a whole new suite of observing software. Together, these have made for a substantial increase in JCMT's capabilities, but a capable system is often complex, and a complex system has lots of places for bugs to hide. Speaking as a TSS, the commissioning process was long and sometimes frustrating (I suspect the hardware and software people would agree), but it was satisfying to see that progress was almost continually being made. HARP and ACSIS were made available to the scientific community in the fall of 2006, and the system has continued to improve to the point where observing with HARP is now more-or-less routine. Just in time, too, as most of the engineering and software effort has been switched over to SCUBA-2 preparations. We will likely be commissioning that beast during 2008, and I imagine that too will be, at times, an arduous process. It will be worth it because, as I am sure you are all aware, the potential is enormous.

What would at any other time be major developments, but which sort of snuck by against the backdrop of all the activity above, was the commissioning and first light for AzTEC and the development of eSMA. Due to the somewhat premature demise of SCUBA, not to mention the delays in construction of the Large Millimetre Telescope, JCMT had the opportunity to host AzTEC in late 2005. Quite a bit was written about the results of that in the last newsletter, so I will not add much except that it was mostly a fun experience to work with the AzTEC team. I think everyone involved was quite pleased with the results. The eSMA project linking JCMT and CSO to the SMA for interferometry continues to progress quietly with a few tests every month or two. Speaking as mostly an outside observer, the progress seems good. (See article in this newsletter.)

As if all the activity at JCMT weren't enough, a massive construction project is now underway to straighten and widen Saddle Road. A six and a half mile section from the summit turn-off leading west towards Waimea has been completed. It is a pleasure to drive; it is the closest thing that I have seen to a real highway in this state. Before deciding to take this route to Kona side, however, you may want to take note that past this section, no work as been done, and the road is in the same state it has been for years. Improving and rerouting that part is for a later phase of the project. They are currently working on the section from the 19 mile marker, roughly the end of the forest, to the summit turn-off. So far, they have done a good job of the destructive part of the project, so be prepared to drive on gravel for several miles, and potentially face construction delays.

To close on a personal note, it seems that I have now been here for three years. It doesn't seem that long, which I suppose says good things about the Joint Astronomy Centre and the JCMT.

(AzTEC, Continued from page 10)

writing, we are in the process of obtaining deep Keck-DEIMOS spectroscopy of potential optical counterparts to 40 SMGs detected over ~0.5 deg^2 of the cluster field (Figure 1). Our multiwavelength observations will then be essential for determining the properties of these 1.1 mm-detected SMGs (regardless of whether they are members of the cluster, or reside at much higher redshift).

Summary

Dust-insensitive observations of star formation in clusters are revealing far more complexity in the evolution of galaxies in biased environments than has previously been thought. The majority of stellar mass assembly in spheroids and bulges is thought to occur at high redshift, but starbursts in clusters at intermediate redshift could also be contributing to the build-up of the red-sequence — *i.e.*, the characterising feature of the galaxy populations of local clusters. Having uncovered a population of moderately star forming galaxies with *Spitzer*-MIPS, we are now searching for the most extreme starbursts within the cluster with AzTEC 1.1 mm mapping. The detection of just one SMG at the cluster redshift would be a significant discovery — dramatically boosting the rate of stellar assembly in an environment traditionally thought to be hostile to star formation.

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The Detection of a Molecular Bipolar Flow in the Multipolar Planetary Nebula NGC 2440

Tatsuhiko Hasegawa, Mei-Yan Wang (*Academia Sinica*), & Sun Kwok (*Hong Kong*)

Our understanding of the morphologies of planetary nebulae (PNe) has undergone a significant change in the last decade. When the effects of projections and ionization are taken into account, the apparent morphologies of many PNe can be explained by an equatorial torus plus two bipolar lobes (*i.e.*, a bipolar structure).

However, optical observations have revealed a number of PNe that cannot be explained by this simple model. Optical images with the Hubble Space Telescope (HST) show that a number of PNe have multiple pairs of lobes (Sahai 2000) and that some PNe with an apparently typical bipolar structure actually have multiple outflow axes. A phenomenological interpretation of these PNe is “multiple episodic flows” or “bipolar, rotating, episodic jets” (BRETS; López et al. 1998).

NGC 2440 (Figure 1) is one of the most dramatic examples of such (optical) multipolar PNe (Kwok 2004). López et al. (1998), based on deep images and slit spectra in the [N II] and [O III] lines, demonstrated the quadrupolar morphology of NGC 2440. We observed NGC 2440 in the *J*=3–2 line with RxB3 on the JCMT. The CO(3–2) emission (Figure 2) traces the cigar-shaped bilobal structure that runs from NE to SW (PA = 35 deg).

Optical and IR images of NGC 2440 show that identifying multipolar lobes in NGC 2440 is not a trivial matter. Selection of a probing line and other cares (data processing, exposure time, *etc.*) significantly affect the identification of a bilobal structure. The CO rotational line turns out to be an excellent probe to identify a single bilobal structure. At the same time, the present CO(3–2) observation clearly indicates that the PA 35 deg bilobe is exceptionally rich in CO in the NGC 2440 system.

There is no detectable velocity gradient in the CO(3-2) line along the CO bilobal structure. The lack of a velocity gradient has also been found in the slit spectra of nebular lines along the optical PA 35 deg bilobal structure by López et al. (1998). The optical spectra show scattered (by dust in the bilobal structure) (red-shifted) line-emissions that strongly indicate dust movements away from the central star at a speed of 150 km/s (López *et al.* 1998). The optical PA 35 deg bilobal structure is therefore a bipolar flow oriented nearly perpendicular to the line of sight.

Optical observers have presented various scenarios about the complex morphology of NGC 2440. According to one plausible scenario (Vázquez *et al.* 1999), a collimated, high-velocity jet emanates from the central star. The postulated jet is episodic and its direction changes with time. The east-west bilobal (bubble-like) structure may have been carved by the jet at an earlier time when the jet axis was in the east-west direction. The jet presumably changed its direction recently in such a way that the jet now intersects with (and blows away) an early torus structure.

The present CO observation is in line with this scenario. In many planetary nebulae, even in an evolved one such as the Ring Nebula, the central torus contains a significant amount of molecular material. If the supposedly recent PA 35 deg lobes contain material that has been blown away from the original, molecular torus, the presence of CO in the lobes can be explained. The lack of CO in the east-west lobes is explained by photodissociation of CO in the old bilobal structure.

These results are discussed in more detail in Wang *et al.* (2007) and Mariappan *et al.* (2007).

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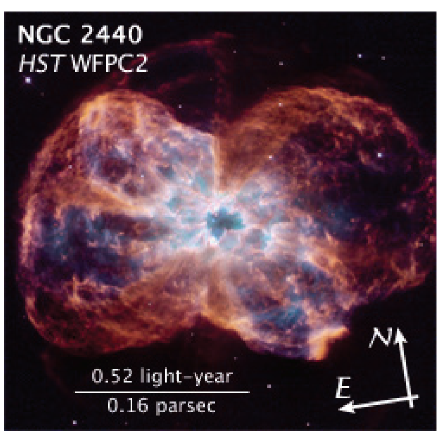

Figure 1. — Three-colour image of NGC 2440 (courtesy of NASA). Red is Hα and [N II], green is [O III], blue is [He II].

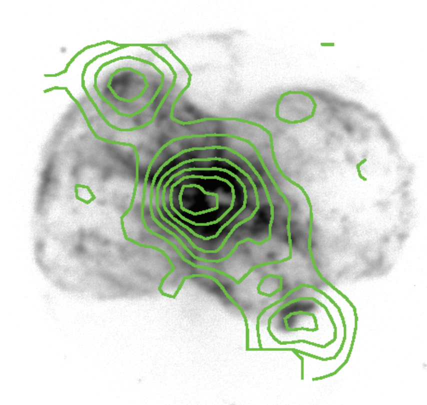

Figure 2. — Greyscale image of [N II] taken at CFHT (Kwok 2004). Contours are of CO(3-2). The lowest contour and the contour interval are both 0.63 K km/s, which corresponds to about 2σ.

Mapping Magnetic Fields in Planetary Nebulae and Post-AGB Stars with SCUBA

Laurence Sabin, Albert Zijlstra (*Manchester*), & Jane Greaves (*St. Andrews*)

The Hubble Space Telescope made famous the round, elliptical, bipolar and point-symmetric shapes of planetary nebulae (PNe) and post-AGB stars (PAGBs). Although there is strong evidence that the departure from spherical symmetry occurs in the AGB phase, one can wonder how from an original sphere we end up with aspherical objects. With the wind-wind interaction (the slower from the AGB and the faster from the post-AGB) and the companion interaction in a binary system, magnetic fields are among the hypotheses used to explain the shapes observed mainly in PNe and PAGBs.

Following Greaves *et al.* (1999), we assume that submillimeter polarisation is due to grain alignment, *i.e.,* in the presence of a magnetic field (**B**) dust grains will be aligned with their long axis perpendicular to the field. Thus the measured angle of polarisation is 90° rotated with respect to **B**. Using SCUBA at 850 and 450 μm, we obtained images of the dust polarisation and, by extension of the **B** field distributions, in four bipolar targets: three planetary nebulae, NGC 6302, NGC 6537 and NGC 7027 and the proto planetary nebula (or post-AGB) CRL 2688.

NGC 6537 (Figure 1) presents a magnetic field mainly localised along the equatorial plane (and hence perpendicular to the outflow). The vectors are consistent with a well defined toroidal magnetic field localised in a circumstellar torus.

The PAGB CRL 2688 (Figure 2) shows the most complicated field structure of the four studied. It covers the whole nebula and presents two distinct orientations: one along the pole and the other along the equator. Some perturbations are also present at the tip of the outflow direction.

In conclusion, we can say that all our nebulae show polarisation indicative of grain alignment by magnetic fields. The three PN present a toroidal field localised at the equatorial plane and CRL 2688 shows a clear poloidal field. The chemistry and the evolutionary phase of the nebulae may play a role in the field structure and distribution. Organisation of the field can also be related to the age of the nebulae, as the magnetic field appears more organised in the older ones (NGC 6537 and NGC 6302). After the poloidal field is carried away with the outflow, the more stable toroidal field would appear. The transition would occur when the equatorial field is wound up through the interaction with a stellar companion. The main shaping agent would therefore be attributed to a binary companion while the magnetic field would take a more important part later on.

More observations are needed to have a clearer idea of the role played by magnetic fields in planetary nebulae and other late type objects. These results are discussed in more detail in Sabin et al. (2007).

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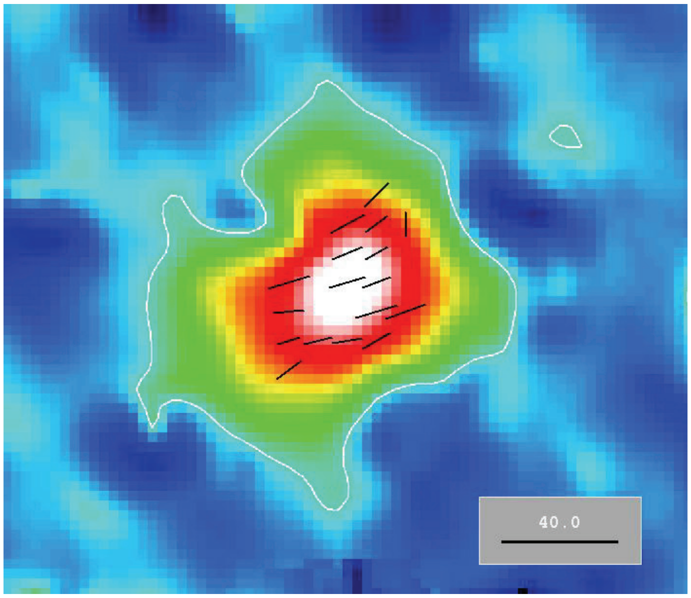

Figure 1. — 850 μm map of the magnetic field distribution in NGC 6537. The bar at the bottom represents the length of a vector of 40% polarization.

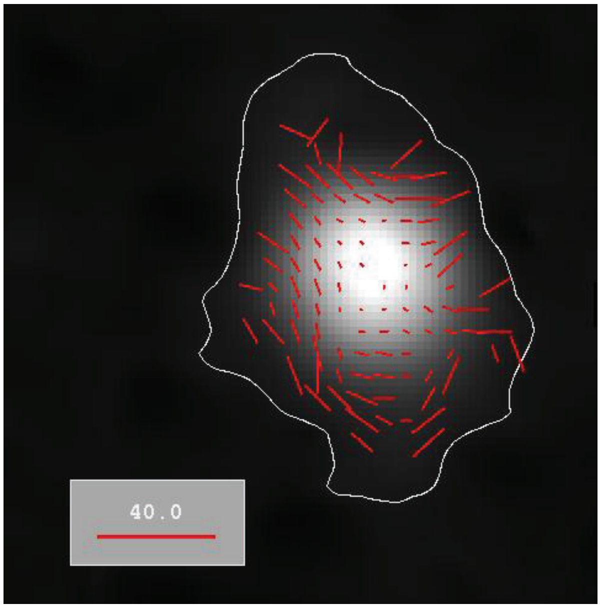

Figure 2. — 850 μm map of the magnetic field distribution in CRL 2688.

CN Emission in the Sgr A* Environment — First Results

Marija Stanković, Ernie Seaquist, Stefanie Mühle (*Toronto*), Asuncion Fuente (*Observatorio Astronómico Nacional*)

The radical CN, through the CN/HCN ratio, is an exceptionally good tool to study photodissociation regions (PDRs; *e.g.*, Fuente *et al.* 2005). The circumnuclear disk (CND) surrounding Sgr A* is exposed to the strong FUV radiation field originating from the central stellar cluster and contains potentially star forming clouds as elucidated by interferometric HCN observations by Christopher et al. (2005). PDR models (Boger & Sternberg 2005) predict that external FUV heating of gas clumps generates photoevaporative outflows and drives strong shocks compressing the gas to higher densities.

As a part of our study of the existence and role of such PDR zones in the global photodissociation of the CND and in promoting or inhibiting star formation, we mapped the CN (*N*=3–2) emission in a 5'×5' area encompassing the CND and its environs using HARP in the raster mode. ACSIS bandwidth of 1 GHz was sufficient to simultanously observe two fine structure components in the CN spectra. A preliminary CN integrated-intensity map and sample spectra are shown in Figure 1. The strongest CN emission corresponds to the most massive cores from the CND. We detect CN emission towards the central pc as well, whereas other molecular species appear to be photodissociated by the strong UV radiation originating from the central stellar cluster, thus implying that the central cavity is not devoid of gas, but that it is heavily photodissociated. Our CN spectra show resolvable fine structure components which provide a diagnostic of the CN optical depth by comparison of their relative intensities within a single rotational transition.

The observations conducted with the JCMT telescope (M06BC06) complement ongoing studies at the lower CN and HCN transitions using the NRO 45 m and the IRAM 30 m telescopes. These data sets at the three different frequencies have similar resolution of 12"–15", thus permitting accurate line ratios to be obtained. To investigate the effects of PDRs on star formation in the CND we will analyse these data using new PDR and radiative transfer models that can constrain the PDR structure and properties in different physical regimes.

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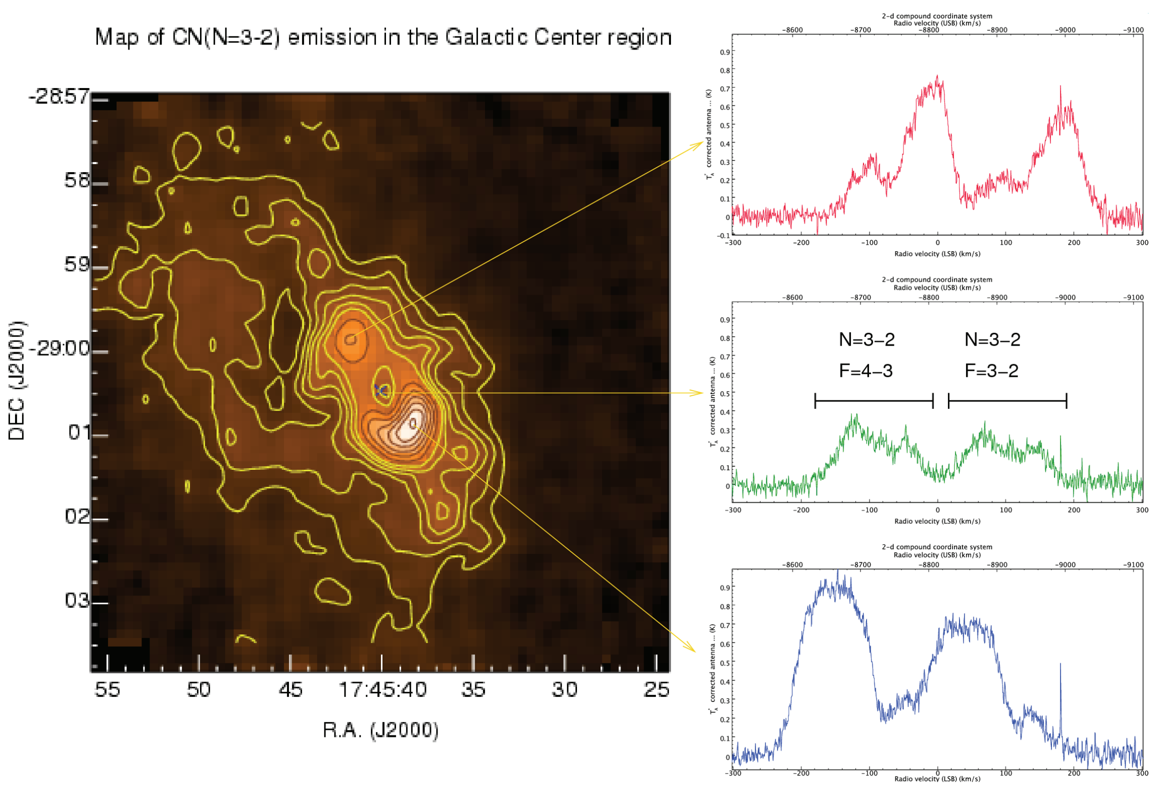

Figure 1. — Preliminary CN(N=3–2) map integrated over all fine and hyperfine transitions of the central 5'×5' region of our Galaxy (left). The observations were conducted using HARP in raster mode and ACSIS with 1 GHz wide bandwidth centered at ν_o=340.136 GHz, in between two fine structure components. This frequency is used as the rest frequency for the velocity scale on the spectra shown next to the map. The contour lines denoted integrated CN(N=3–2) intensities of (5,7,9...15,19,23...39)×5 K km/s. The position of Sgr A is marked with a blue cross. The CN(N=3–2) spectra at selected positions indicated in the map are shown on the right.*

Mid-Infrared Spectral Diagnosis of Submillimetre Galaxies

Alexandra Pope (*UBC*), Ranga-Ram Chary (*Cal Tech*), David Alexander (*Durham*), Lee Armus (*Cal Tech*), Mark Dickinson (*NOAO*), David Elbaz (*Saclay*), David Frayer (*Cal Tech*), Douglas Scott (*UBC*), & Harry Teplitz (*Cal Tech*)

Perhaps the most enigmatic members of the high redshift galaxy population are the submillimeter (submm) galaxies (SMGs). Initially discovered about a decade ago with SCUBA on the JCMT, they have proven to be challenging to study, due to the relatively large JCMT beamsize and the faintness of the counterparts at most other wavelengths (*e.g.*, Ivison *et al.* 2002). Nevertheless, it has become clear that they are very massive systems (*e.g.*, Swinbank *et al.* 2004; Borys *et al.* 2005; Greve *et al.* 2005) at *z~1–4* (Chapman *et al.* 2005; Pope *et al.* 2005, Aretxaga *et al.* 2007) which are thought to be connected with the most massive present day galaxies, as well as to quasars, via an evolutionary sequence (*e.g.*, Lilly *et al.* 1999). A crucial issue in understanding these connections is determining what powers the extreme infrared (IR) luminosities of SMGs: active galactic nuclei (AGN) or star formation (SF)?

In order to better understand the SMG population, we have targetted about a dozen SMGs in deep integrations with the Spitzer Space Telescope's Infra-Red Spectrograph (IRS). Our sample was selected from sources in the Great Observatories Origins Deep Survey (GOODS) North field, specifically from those SMGs having secure multi-wavelength counterparts in our GOODS–N SCUBA 'Super-map' (Borys *et al.* 2003; Pope *et al.* 2006). We find strong PAH emission in all of our targets, which allows us to determine mid-IR-based spectroscopic redshifts, as well as placing constraints on the SF *vs* AGN contributions to the mid-IR emission (and by inference the observed submm). We study the ensemble properties of the SMGs by averaging together the individual mid-IR spectra in the rest-frame (Figure 1a). We can fit this average spectrum to a model containing a starburst PAH component plus an AGN continuum component, together with extinction applied to both. We find that the mid-IR luminosity of SMGs is clearly dominated by SF, with a maximum mid-IR AGN contribution of 30%. Overall the mid-IR spectra of SMGs are similar to a scaled (*i.e.*, much brighter) spectrum of the local starburst galaxy M82.

We also fit the mid-IR spectra of the SMGs together with the submm and radio photometry using template spectral energy distributions (Chary & Elbaz 2001). The best-fit models have cool dust temperatures (<*T*>=32 K) and high total IR luminosities (L_{IR}) which imply SF rates of ~700 $M_{\odot}$/yr. We find that high redshift SMGs lie on the same relation between L_{IR} and $L_{PAH\,6.2}$ which has been established for local starburst galaxies (Figure 1b). This suggests that PAH luminosity can be used as a proxy for SF rate in SMGs.

Local ultra-luminous IR galaxies (ULIRGs), which are often considered as the low-*z* analogues of SMGs appear to be deficient in PAH luminosity for a given L_{IR} as compared to local starburst galaxies and SMGs. We also find that the mid-IR properties of SMGs differ from those of typical 24 μm-selected ULIRGs at *z~2* (Sajina *et al.* 2007); the former are mainly dominated by SF, while the latter are a more heterogeneous population, including a significant fraction showing strong AGN activity. This difference might be explained through an evolutionary scenario, in which SMGs are an earlier, cooler phase in the massive merger process, when the AGN has not yet become strong enough to heat the dust and dilute the PAH emission.

Full details of the work reported here can be found in Pope *et al.* 2007.

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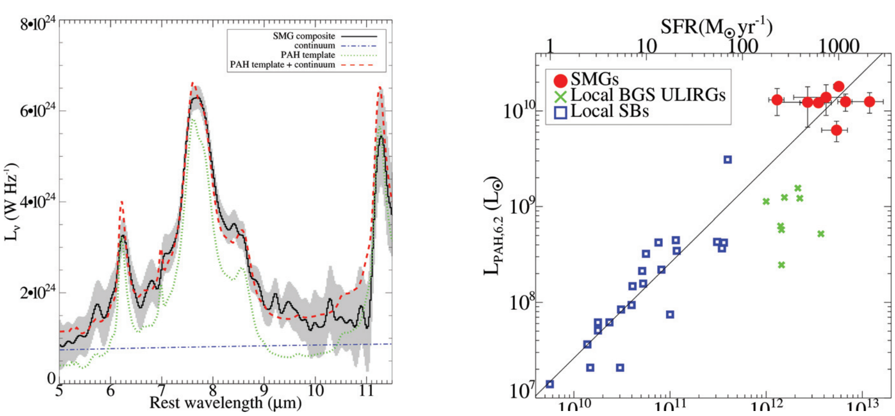
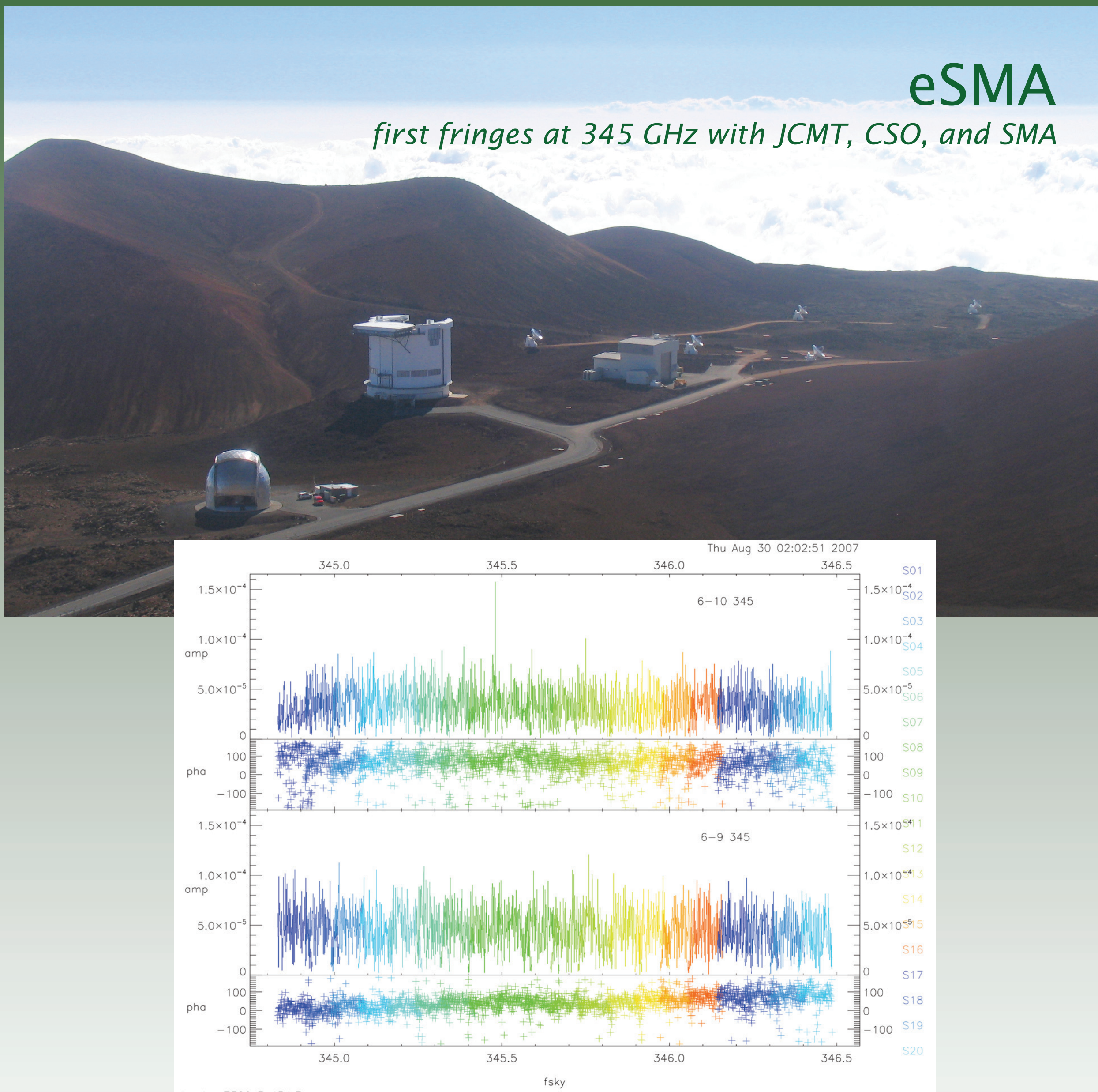


Figure 1. — (left) SMG composite mid-IR spectrum (black curve) smoothed by a Gaussian with a full width at half maximum (FWHM) of 0.12 μm which corresponds to the average instrument resolution. The shaded region shows the 1σ uncertainty. The red curve is the best-fit model which is composed of a PAH template (green curve) and a power-law continuum component (blue curve), each with extinction applied to them. (right) Correlation between L_{IR} and the 6.2 mm PAH luminosity. SMGs are denoted by the large red circles while the local starbursts (Brandl et al. 2006) and the Bright Galaxy Sample (BGS) ULIRGs (Armus et al. 2007) are shown by the blue squares and green crosses, respectively. The line shows the best-fit relation for the local starburst galaxies.



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