JCMT NEWSLETTER

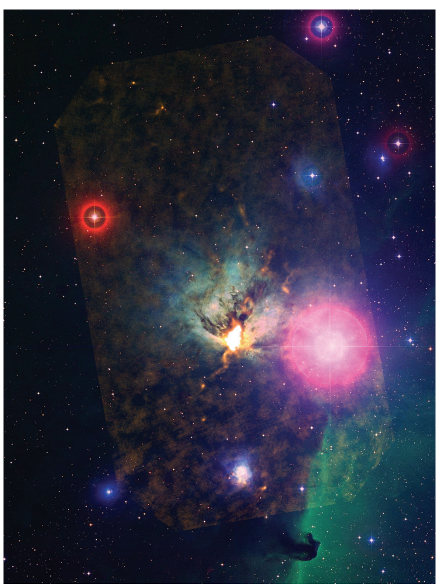
JAMES CLERK MAXWELL TELESCOPE

AUTUMN 2010 · #33

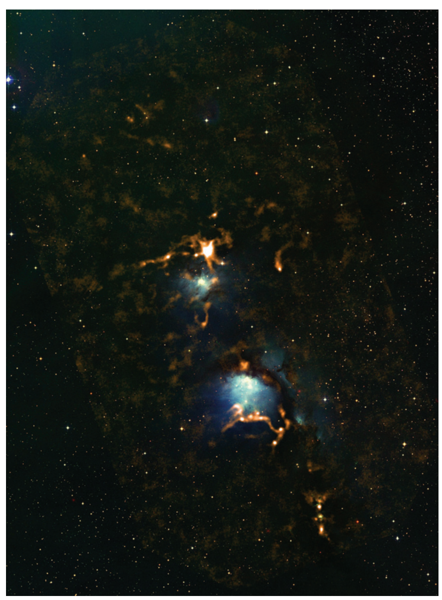
SCUBA-2 Recommissioning

SCUBA-2 Array Upgrade

In This Issue



On the front cover: SCUBA-2 S2SRO and optical DSS composite image of the Horsehead Nebula in the Orion B Molecular Cloud Complex. Cold clouds of gas and dust from SCUBA-2 appear orange in this image, superimposed onto an optical background of stars and nebulosity. (Also see article on page 8 of this issue.) (Image courtesy David Nutter/Cardiff and the JLS Gould Belt Survey Consortium).



On the rear cover: SCUBA-2 S2SRO and optical DSS composite image of molecular clouds in the Orion B Molecular Cloud Complex. Cold clouds of gas and dust from SCUBA-2 appear orange in this image, superimposed onto an optical background of stars and nebulosity. (Also see article on page 8 of this issue.) (Image courtesy David Nutter/Cardiff and the JLS Gould Belt Survey Consortium).

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The Joint Astronomy Centre provides services and support to enable community and staff astronomers to undertake top-quality, front-line international-class research using the James Clerk Maxwell Telescope (JCMT); to develop the JCMT in order to maintain its position as the most advanced observatory of its kind in the world; to operate the United Kingdom Infrared Telescope (UKIRT) in a streamlined mode so as to expeditiously complete the world-leading UKIDSS programme, plus other programmes as resources permit; to operate both facilities 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 organisations.

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

Good news! After many years of hard work, false starts, troubleshooting and schedule hold-ups for the most incredible reasons, the full set of detector arrays for SCUBA-2 was finally delivered to Hawaii this past summer. The eight-week engineering programme to install the arrays, assemble the instrument, mount it on the telescope and cool it to operating temperature was completed successfully, on schedule and with no technical issues arising. The instrument was cold and ready for use on 7 October. The re-commissioning programme has commenced and the early results are very encouraging: we are quietly hopeful that the technical improvements that have been made to the system since the shared-risks observing campaign earlier this year will result in significant gains in performance. Of course we won't know this for sure until the on-sky commissioning takes place in early 2011. To keep the community informed of progress, we have set up a news blog at `http://scuba2.wordpress.com/` . Check it out.

In parallel with the technical work on the instrument, we have been working with the PIs of the SCUBA-2 Shared-Risks Observing (S2SRO) projects to appraise them of the latest updates to the pipeline software and data products, and also to receive valuable feedback on the quality of those products. This has resulted in the continued development of the ORAC-DR pipeline, the map-making routine within the Starlink SMURF package, and a data reduction cookbook. All the S2SRO data were reduced on the grid machines at the CADC, where the JCMT Science Archive (JSA) is hosted, and the reduced products made available to the PIs. As an indication of the data management challenge that SCUBA-2 poses, the raw and reduced data that were generated by the six weeks of S2SRO now occupy 13% of the whole JSA. The proprietary period for the S2SRO data expired on 5 November and several of the PIs are now writing up their results for publication. Some of these results are described in articles in this *Newsletter*.

We are also pleased to report that we took delivery this summer of two ancillary instruments which will operate in conjunction with SCUBA-2: FTS-2, a Fourier transform spectrometer, and POL-2, a polarimeter. Both were built in Canadian university laboratories with Canadian funds, but when commissioned they will be available as common-user instruments for the entire community. These two instruments will enable entirely different scientific studies to be undertaken, including the role of magnetic fields in star formation, the emission properties of dust, and line contamination of SCUBA-2 photometry; the combination of SCUBA-2 and its ancillary instruments will be unrivalled anywhere in the world.

Planning processes are underway in two of the partner countries. The UK government recently announced the outcome of its comprehensive spending review, and although the overall settlement for science appears to be much better than we had been led to anticipate, the devil is very much in the detail and we won't know how STFC fared until December or January. In Canada, the community has been developing its Long-Range Plan for Canadian astronomy, and this will be a major driver of NRC's strategy for supporting its overseas telescopes. We await the outcomes of these two processes with considerable interest, since they will both have direct impacts on the long-term future of the JCMT.

Antonio Chrysostomou, Associate Director JCMT

The fault rate at the telescope is an important performance metric for the observatory as it directly measures how facility faults impact the delivery of the science programme, and the JCMT Board have set a fault rate of 5% as a target. Of course, it is our aim to come in significantly below this, so it's a pleasure to report that the fault rate has been slowly decreasing over the last few years and that this trend continues. During the 6-month period between April and September 2010, the fault rate was just 3.7%. There are various reasons for this, and one is the prompt and professional response to faults when they do occur by the JAC support staff.

Another statistic that we track, but over which we have no influence, is the amount of time lost to weather. The weather has been exceptional on Mauna Kea over the last year or so, and in this time period, the JCMT lost just 2.6% of the available time to bad weather. This is unheard of. See the article in this issue by Head of JCMT Operations, Dr Remo Tilanus, which goes into more detail.

We usually conclude this column with a summary of staffing changes. In a change of format, this is now covered in a separate article by our new *Newsletter* editor, Dr Chris Davis. Chris is a Senior Support Astronomer at the JAC, having spent many years as a support scientist for UKIRT; as part of the large-scale changes happening at that telescope, he recently transferred over to the JCMT to fill a vacancy created when Dr Ming Zhu returned to Canada. We are delighted to have him.

The JLS SCUBA-2 'All-Sky' Survey (SASSy) Project

Todd Mackenzie, Filiberto Braglia, Andy Gibb, Douglas Scott (*UBC-Vancouver*), & The JLS SASSy Consortium

The submillimetre window allows us to study the youngest phases of star formation in our Galaxy, and the dusty, most prodigiously star-forming galaxies at high redshift. Despite this strong motivation, the submillimetre sky still remains poorly surveyed. The SCUBA-2 'All-Sky' Survey, or SASSy, is a JCMT Legacy Survey project designed to redress this balance and exploit the rapid mapping capability of SCUBA-2. The goal is to map a large portion of the sky visible from the JCMT with an angular resolution of 14 arcsec at 850 μm down to a noise level of 30 mJy/beam.

The benefits of such a wide-field survey are many, ranging from a complete census of infrared dark clouds (IRDCs) to the potential discovery of some of the most luminous high-redshift galaxies in the Universe. The approved phase of SASSy consists of two distinct parts: a strip covering the Galactic Plane which is visible from Hawaii; and a 'Pole-to-Pole' strip perpendicular to this and designed to pass through the Galactic and Ecliptic North Poles. These observations will be carried out in 'grade 4' weather conditions, *i.e.*, essentially when the atmosphere is too opaque to enable useful observations of fainter objects.

Data on two fields were obtained for a quarter square degree field centred on NGC 2559, a nearby dwarf galaxy, and for a one square degree field centred on W5-E, a star-forming region within the Galactic Plane. Both fields required only a few hours of observing time and the results demonstrate the great improvement in mapping speed when compared to the original SCUBA instrument.

In the field containing NGC 2559, we are able to robustly identify (at about 7σ) a source coincident with the central region of the galaxy that matches closely the position of the radio source NVSS 081705-272724 (see Figure 1). The rest of the region is devoid of high-significance sources. Although we knew in advance that this galaxy would be detectable, the data set was treated just as if it was part of the overall SASSy project, and the preliminary version of the pipeline was able to 'discover' the source. This is the first known submillimetre detection of NGC 2559.

The W5-E region is much busier, with many clumps and filaments visible in the map (see Figure 2, which shows the SCUBA-2 image overlaid with 70 μm Spitzer contours). Known sources, such as the HII region Sh-201 and the massive young stellar object AFGL 4029, are clearly detected. The field also contains two bright-rimmed clouds observed previously with SCUBA. An indication of SASSy's source-finding capability is seen in the detection of new submillimetre sources associated with two other bright-rimmed clouds, one of which shows no 24 μm emission and is only weak at 70 μm (see Figure 3).

Each of the two fields required only a few hours of observing time and together they demonstrate the great improvement in mapping speed when compared to the original SCUBA instrument. When its full complement of arrays is in place SCUBA-2 should enable SASSy to carry out a shallow survey over an ambitiously large region of sky, cataloguing many interesting new sub-mm sources. More information can be found in the paper detailing the pilot study at arXiv:1012.1655.

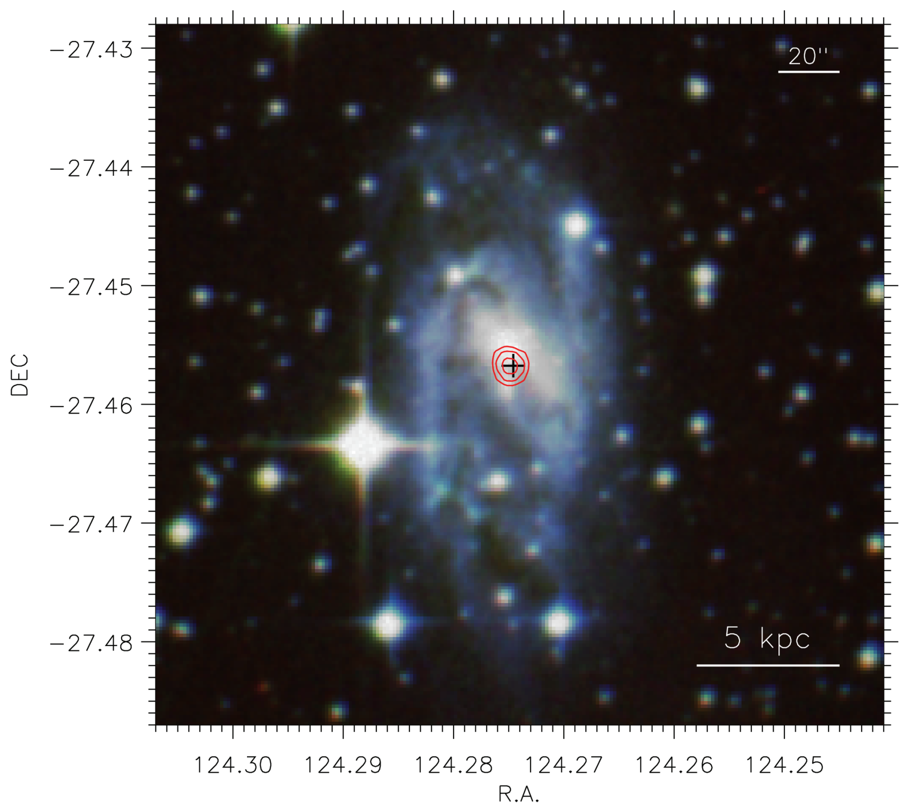

Figure 1. — SCUBA-2 850 μm contours overlaid on an optical RGB image of NGC 2559 (derived from DSS data). The black cross marks the position of the NVSS radio source.

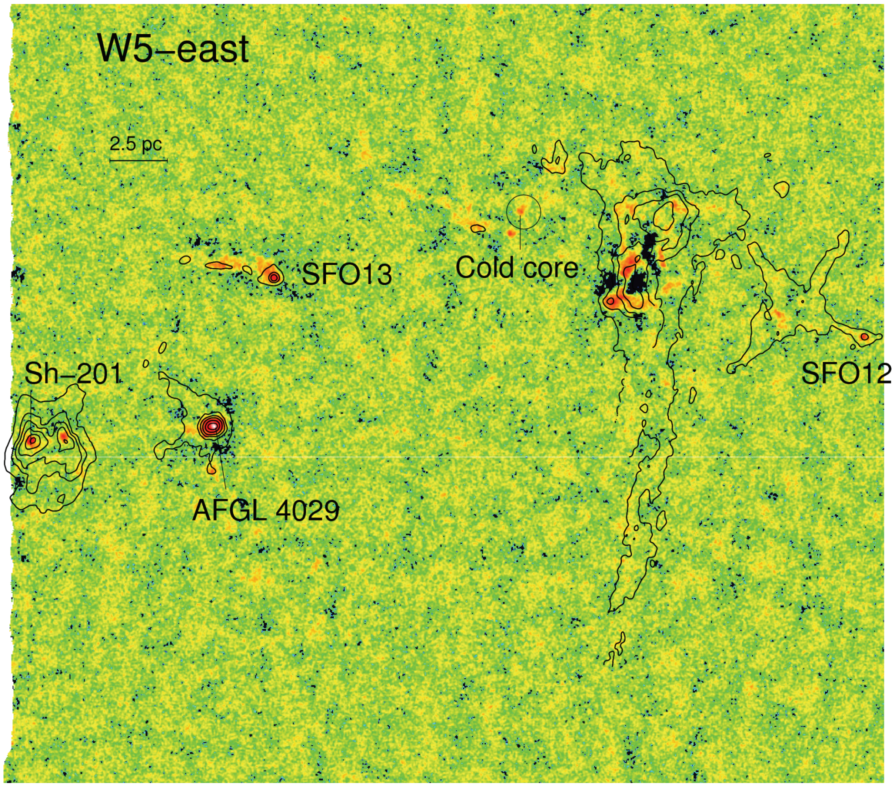

Figure 2. — SCUBA-2 850 μm map of W5-E, with Spitzer 70 μm contours overlaid. The circle labelled 'cold core' is shown in more detail in Figure 3.

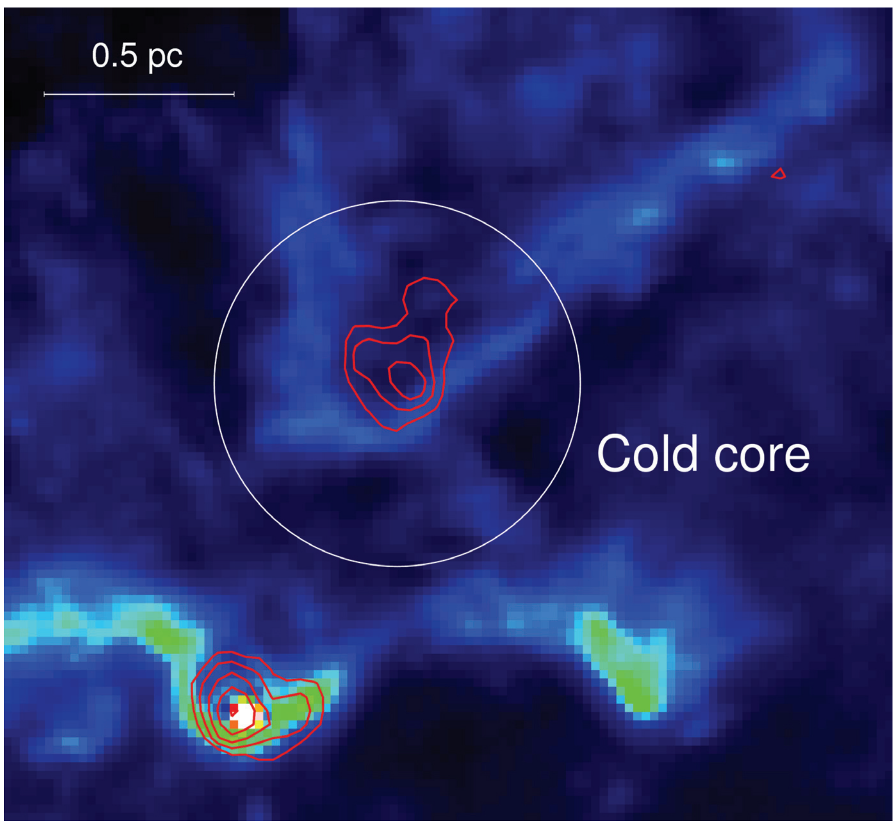

Figure 3. — SCUBA-2 contours of W5-E, overlaid on a Spitzer 24 μm image. The source labelled 'cold core' (see Figure 2) is circled and shows up clearly in the submillimetre, yet lies within a dark region of the Spitzer image. It is, however, detected at 70 μm with Spitzer.

S2SRO Observations of the Rosette Molecular Cloud

James Di Francesco (*NRC-HIA*), Sarah Sadavoy (*Victoria*), Nicola Schneider (*CEA-Saclay*),
Sylvain Bontemps (UBordeaux), Frederique Motte (*CEA-Saclay*),
Frossie Economou (*JAC*), & Martin Hennemann (*CEA-Saclay*)

The Rosette Molecular Cloud (RMC) is at a distance of 1.6 kpc (Johnson 1962; Pérez et al. 1987; Park & Sung 2002) and lies southeast of the well-known Rosette Nebula, NGC 2237. Most recently, Dent et al. (2009) observed CO 3-2 emission over the RMC with HARP (see *JCMT Newsletter*, #26, Spring 2007). The RMC is being impacted by an expanding bubble powered by the O stars within the Rosette Nebula, making it an interesting study of triggered and in-situ star formation at high masses. As part of the SCUBA-2 Shared-Risks Observing campaign in February-March 2010, a ~1 deg^2 field of the RMC was observed in grade 3 weather. A mean 850 μm sensitivity of ~46 mJy/beam was reached across the map after ~5 hr of fast scanning via a "rotating pong" pattern over 11 tiles, each 20×20 arcmin in size. The data were reduced using the SCUBA-2 reduction pipeline.

Figure 1 shows a close-up of 18-20 compact protostellar objects detected at 850 μm. These objects are associated with embedded clusters PL 4, PL 5 and PL 6 (Phelps & Lada 1997). The bright object at lower left is AFGL 961, a.k.a. the "Rosette Eye," a massive young stellar object where ionizing radiation has allegedly just pierced its dusty surroundings (Li et al. 2008). The objects at upper right were first seen in early Herschel SPIRE/PACS observations at 70-500 μm, and identified from their spectral energy distributions (SEDs) as Class 0 protostars (Hennemann et al. 2010, Motte et al. 2010).

The SCUBA-2 data will allow us to probe accurately the masses of the compact dusty envelopes surrounding these young stellar objects. With the Herschel data, the 850 μm data give us a significant "lever-arm" with which the SEDs of each protostellar object can be fit with greybodies. Specifically, the longer wavelength and similar resolution of the SCUBA-2 data relative to those from Herschel allow us to constrain the power-law index of the dust opacity/frequency relationship, *i.e.*, β. (Unfortunately, the requested weather for these observations precluded acquistion of 450 μm data, to fill out further the SEDs.) With better constraints on β, more accurate envelope masses can be determined, and this knowledge will improve the location of each object on a protostellar evolution diagram. Analysis of these exciting new SCUBA-2 data is ongoing.

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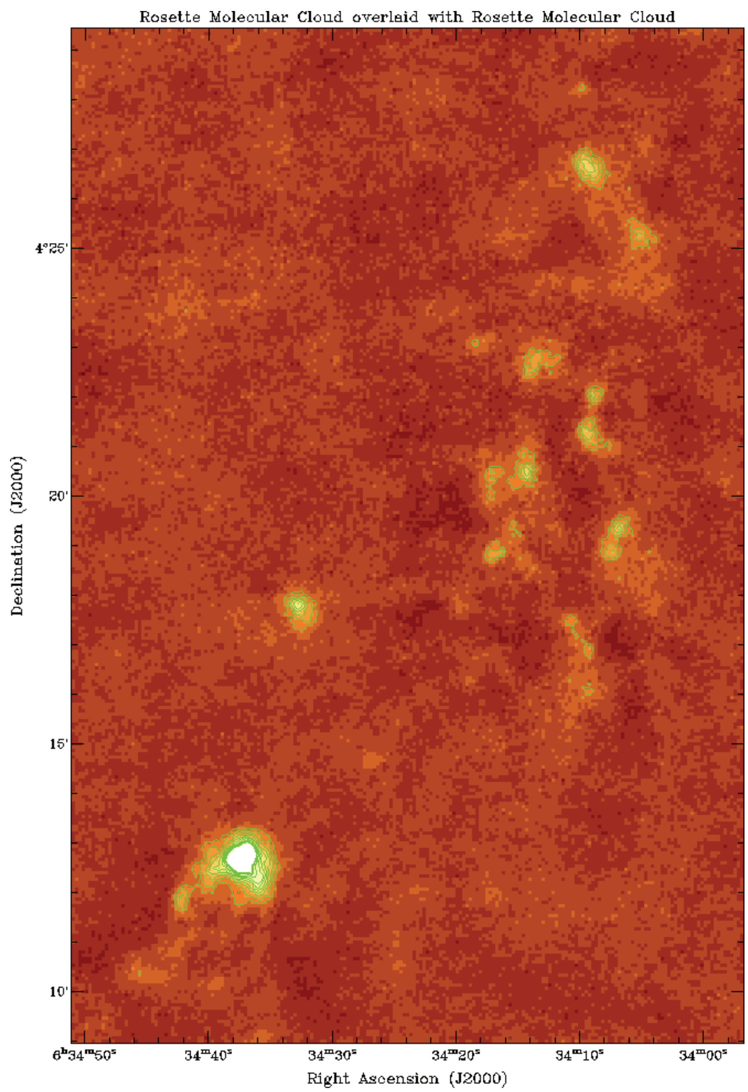
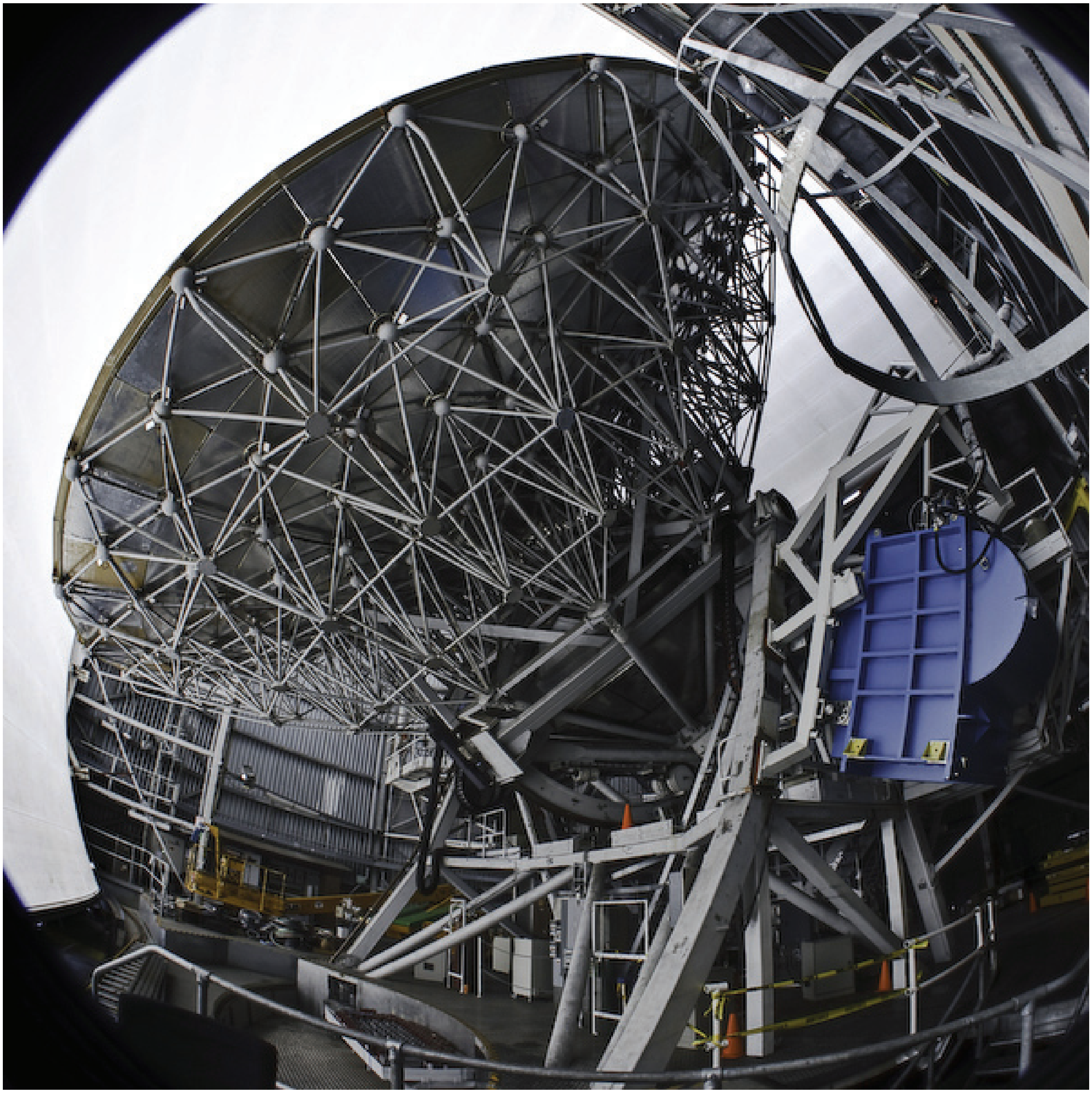


Figure 1. — SCUBA-2 850 μm map of compact protostellar objects in the Rosette Molecular Cloud.



SCUBA-2 on JCMT. (Image courtesy Antonio Chrysostomou/JAC.)

S2SRO Mapping of Orion B

David Nutter (*Cardiff*) & The JLS Gould Belt Survey (GBS) Consortium

We have mapped two regions of the Orion B star-forming molecular cloud using SCUBA-2 (Holland et al. 2006) during the Shared-Risks Observing (S2SRO) time earlier this year, when one of the four sub-arrays at each wavelength was installed in the instrument.

The two regions observed contain the main extinction peaks in Orion B. They cover the majority of the A_V>3 material, and approximately half of the A_V>2 material. The northern map (Orion B-North) is centred on $5^h\ 47^m\ 00^s$, 0° 15' 00"', while the southern map (Orion B-South) is centred on $5^h\ 41^m\ 50^s$, -1° 48' 00". Images generated from these data and optical DSS observations are shown on the covers of this *Newsletter*.

Both maps were observed as eight circular fields, each tile made by repeatedly mapping a 20 arcmin square, with a rotation between each repeat. Each tile has a diameter of 28 arcmin. After co-adding, the two maps each have an area of 1.3°×0.8°, and represent approximately 4 hr of integration time each. These maps are a factor of three larger than previous submillimetre maps of the region, and yet were observed in less than one fifth of the time. A portion of the map of Orion B-North is shown in Figure 1.

As a result of varying weather conditions during the observations, together with the overlapping necessary to tile circular maps, the noise level in the data is not constant. It varies from approximately ~20 mJy/beam in the centre of the maps, to around 60 mJy/beam at the edges. Approximately 50% of the mapped area has an rms noise level that is below ~40 mJy/beam.

A portion of the mapped region was also covered, to a similar depth, with the SCUBA camera on the JCMT (Motte et al. 2001; Johnstone et al. 2001, 2006; Nutter & Ward-Thompson 2007). In order to compare the sensitivity and calibration of the new data, the flux densities from a number of objects were measured in both the SCUBA and the SCUBA-2 data. Figure 2 shows the comparison of the integrated flux densities from these sources. The scatter of the data about the 1:1 line is very low, indicating that the consistency is very good. In order to make the data match the 1:1 line, a flux conversion factor (FCF) of ~680 mJy/beam/pW was used. This calibration is higher than the recommended one, but is within the current uncertainty in the FCF of SCUBA-2 (Chapin et al. 2010).

The consistency of the structure in the two datasets is shown in Figure 3. This image shows a portion of the Orion B-South SCUBA-2 map smoothed to a resolution of 16.5 arcsec. The 1σ rms noise in this smoothed map is ~15 mJy/beam. The colour-table in this image has been stretched to highlight the faintest structures. The SCUBA-2 data have been overlaid with a 30 mJy/beam contour from the original SCUBA data. As well as the bright sources being seen in both datasets, the very faint structures are detected in both, showing the same position and morphology. Indeed, almost all of the structures that we can see in the map are seen in both datasets. Since the method of mapping the sky is very different for SCUBA and SCUBA-2, it is clear that these faint sources cannot be mapping artifacts, and must therefore be real

(Orion B, continued on page 9)

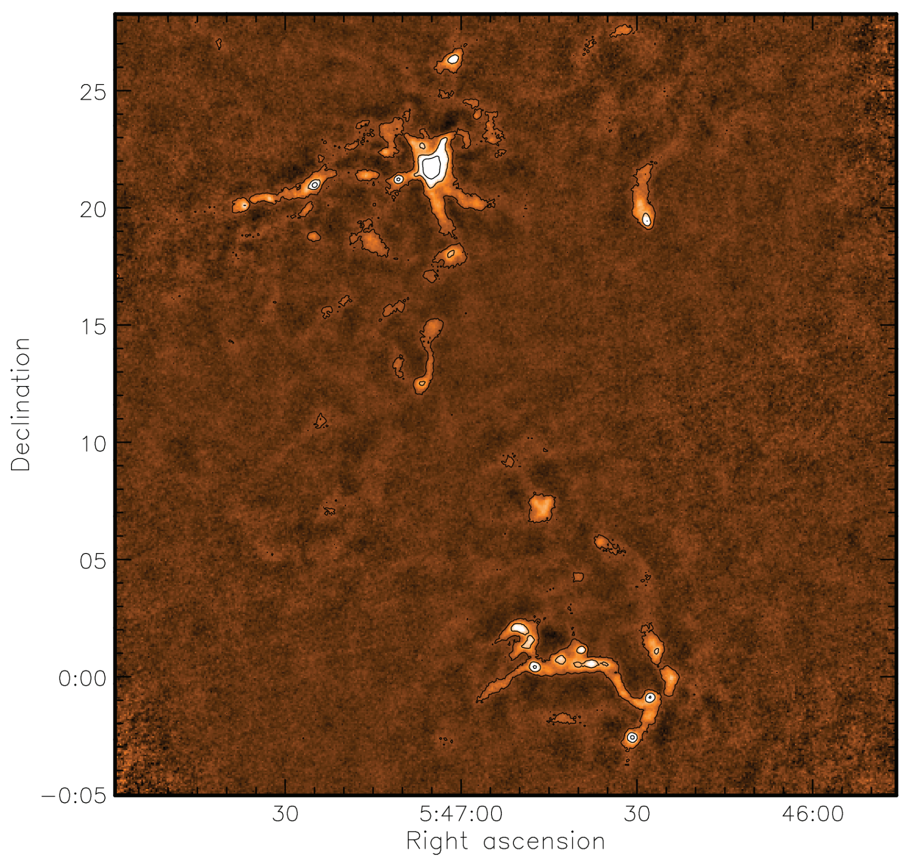


Figure 1. — A portion of the SCUBA-2 map of Orion B-North. The data are scaled between -100 and 400 mJy/beam. The contour levels measure 3, 15 and 40σ.

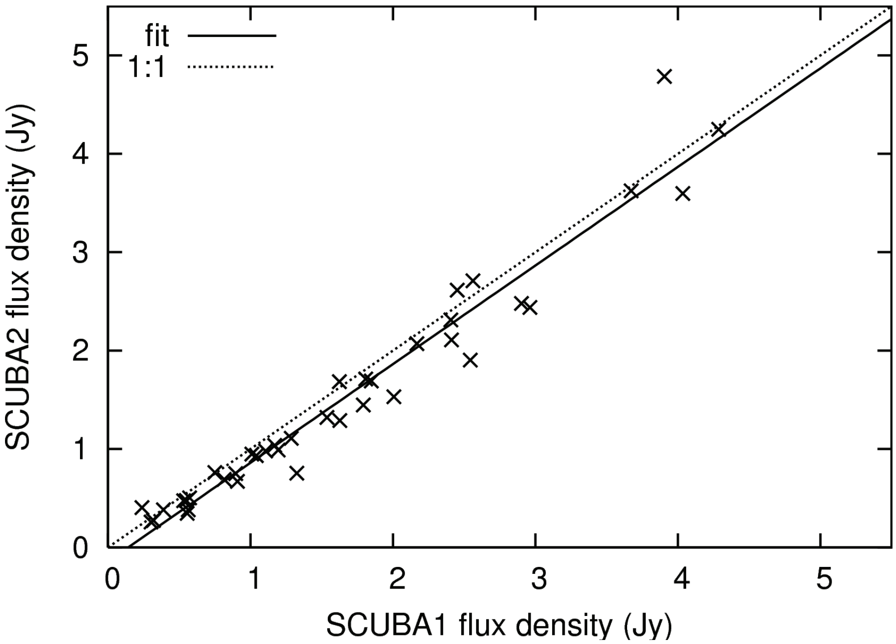


Figure 2. — A comparison of the SCUBA and SCUBA-2 integrated flux densities for a number of sources in Orion B-North. The solid line shows the best fit to the data. The dotted line shows the 1:1 relation.

(Orion B, continued from page 8)

structures. Further study will be required to determine whether these are bound structures. If they are, then with only 8 hr of SCUBA-2 data we will have pushed the core mass function of prestellar cores in this region to lower masses than was achieved with the many nights of observing time needed to construct the original SCUBA maps.

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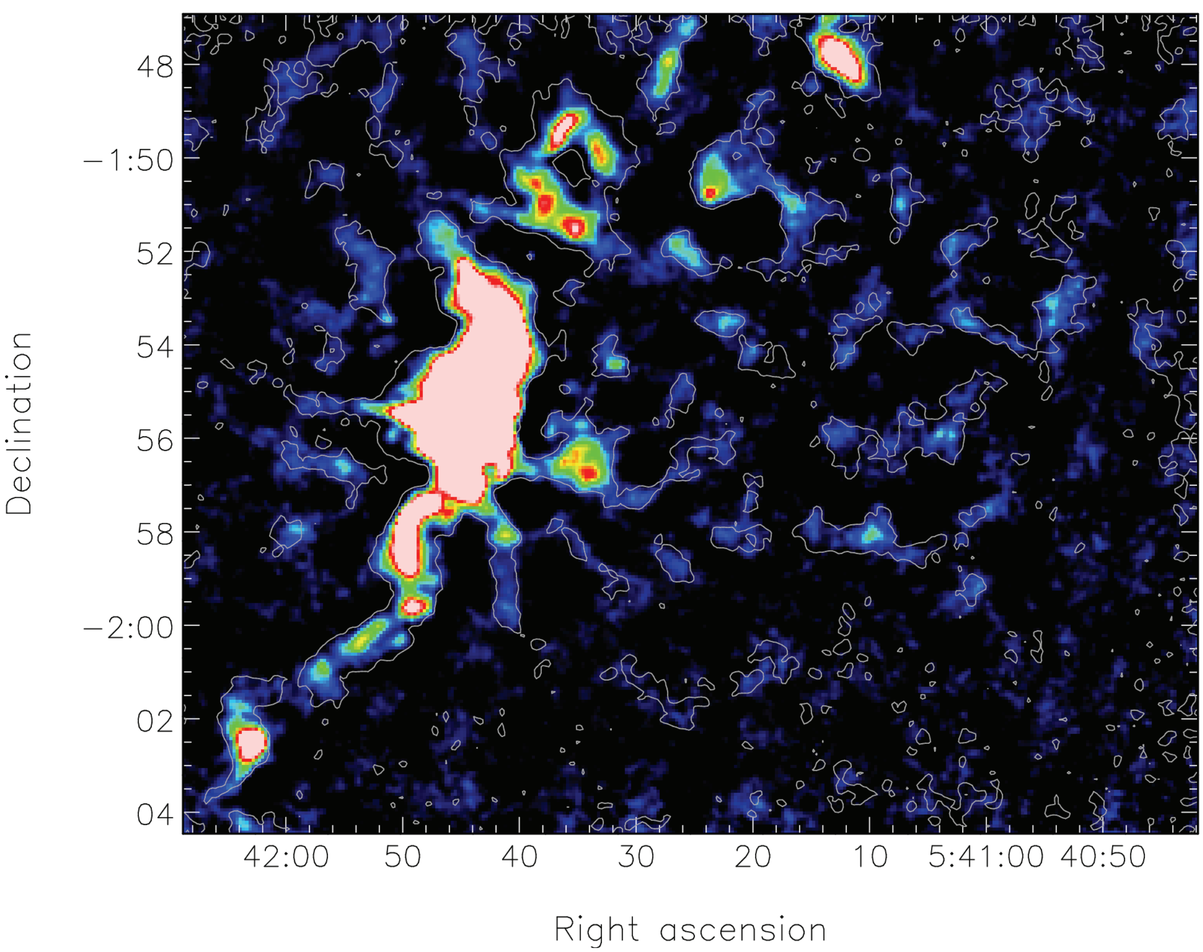


Figure 3. — An enlarged view of a portion of Orion B-South SCUBA-2 map with the colour-table scaled from 0 to 300 mJy/beam (15σ) to highlight the fainter material. The SCUBA-2 image is overlaid with contours showing SCUBA observations of the same region (Nutter & Ward-Thompson 2007); the single contour level is set at 30 mJy/beam (1.5σ). The correspondence between the two datasets is striking.

SCUBA-2 Array Upgrade and Recommissioning

Wayne Holland (*SCUBA-2 Project Scientist/Edinburgh*)

Most readers will be aware that over the summer SCUBA-2 was (finally!) upgraded to its full complement of 8 arrays. This represented the culmination of a long, and sometimes highly challenging, array development programme that started back in earnest in 2004. With over 10,000 bolometers now in two focal planes this will finally allow the instrument to fulfil its potential as the premier wide-field survey instrument in the submillimetre. Much of the array fabrication work was actually happening "behind the scenes", at various institutions around the world, as the main SCUBA-2 instrument was initially commissioned with only one science-grade (S-G) array at each waveband. Following the S2SRO observations earlier this year, these two S-G arrays were also sent back to Edinburgh to be "upgraded" themselves.

Technical Challenges

Despite early optimism ("what can possibly go wrong, it's all just tried-and-tested fabrication steps from now on") it has proven very difficult to attain a high level of quality control over the many process steps associated with the array manufacture. To a certain extent this was to be expected, since although many of the steps were indeed reasonably well-characterised processes, bringing all of these together to produce an array has proven far from straightforward. It is also true that not that many arrays have actually been made. That, coupled to the fact that it is a lengthy process, has meant that the project has never had the "luxury" of being able to eliminate errors and improve upon designs via a series of next generation devices (as was the case for infrared arrays). In 6 years we've effectively gone from a single pixel to being able to produce arrays that each have over 1000 bolometers.

The various processes involved in array fabrication, not to mention the many trips across the Atlantic the parts have been subjected to, is well chronicled in an ever-so-scary flow-chart diagram that appears in Holland et al. (2006). Without going too deeply into the gruesome details, the arrays start off as plain silicon wafers and are subjected to fusion bonding, grinding, various alignments and metallic depositions, hybridisation (bonding the "detector" and "MUX" wafers together), deep etching using plasmas to separate the individual bolometers, laser dic-

(SCUBA-2 Array Upgrade, continued on page 11)

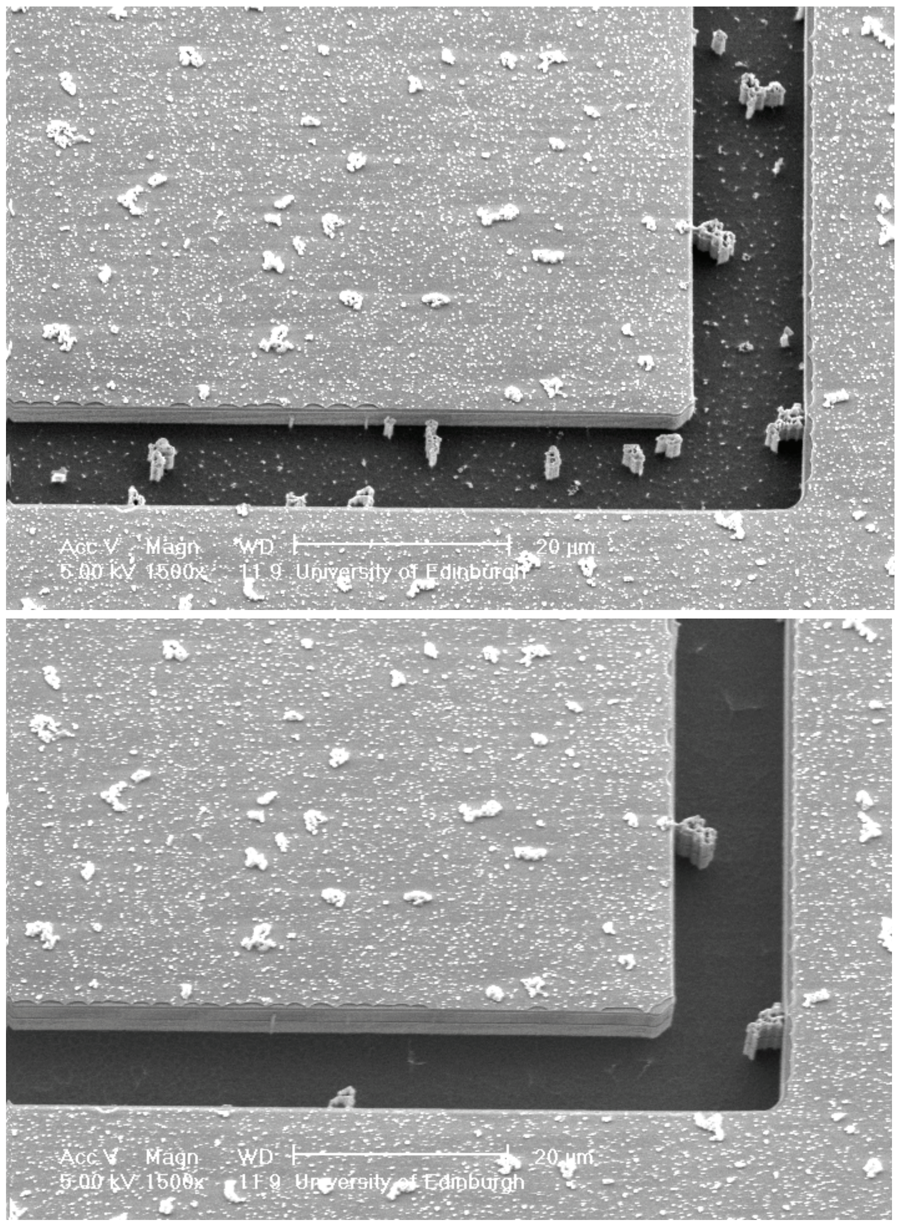


Figure 1. — Scanning electron microscope images of a small section of an array showing the particulate contamination. The darker coloured 10 µm-wide trench is the critical area to keep clean as that provides the thermal isolation between the bolometer and silicon support structure: (top panel) before snow-jet cleaning, (bottom panel) after cleaning.

(SCUBA-2 Array Upgrade, continued from page 10)
ing, precision epoxy bonding to a copper hairbrush support, and finally wire bonding to cold electronics modules. Given all this work, together with the relatively small number of devices developed, it's perhaps a minor miracle that a decent quality has been produced at all!

One example of a recent problem which beset the array work is what became known as the "weed issue". Figure 1 shows a tiny section of an array contaminated by dark particulates. These particulates, thought to have been produced in an earlier processing stage, masked the plasma etch that would eventually isolate each bolometer from its neighbours. "Weeds" would be produced that could thermally short circuit bolometers together, particularly if they fell over in one of the 10 μm-wide trenches. The particulate density was so bad that a special cleaning method needed to be developed involving a "snow-jet" clean (a pressurised stream of CO_2 and nitrogen). This proved to be a very effective solution to the problem.

Despite all of the problems the remaining arrays were completed and show yields, based on room temperature electrical measurements, of >90%. Figure 2 shows a close-up of one of the arrays after being diced into a rectangular shape from the original circular wafer.

Cold Electronics Re-Design

One of the key challenges for SCUBA-2 has always been to ensure that the low-temperature thermal design allows sufficient cooling power to operate all 8 arrays, with minimal heat leaks from higher temperatures. However, this is easier said than done, as even the tiniest heat leaks (a few microwatts) can scupper the thermal balance of the system. For the two S-G arrays operating during S2SRO there was a very obvious temperature gradient across the arrays which resulted in lower bolometer yield and poorer sensitivity (the latter due to the fact that not all bolometers were operating at their most optimum bias points). The gradient was caused by a heat leak that came via the signal and bias lines from the cold electronics module at 1 K. At the same time that the remaining arrays were being produced, the wiring on the cold electronics module (CEM) was also redesigned. The wires were changed to niobium-titanium, coated with a phosphor bronze alloy, and evidence from re-commissioning so far suggests that this design change has significantly reduced the heat leak from 1 K. Figure 3 shows a CEM connected to an array, highlighting the new ribbon cables between 1 K and ~100 mK.

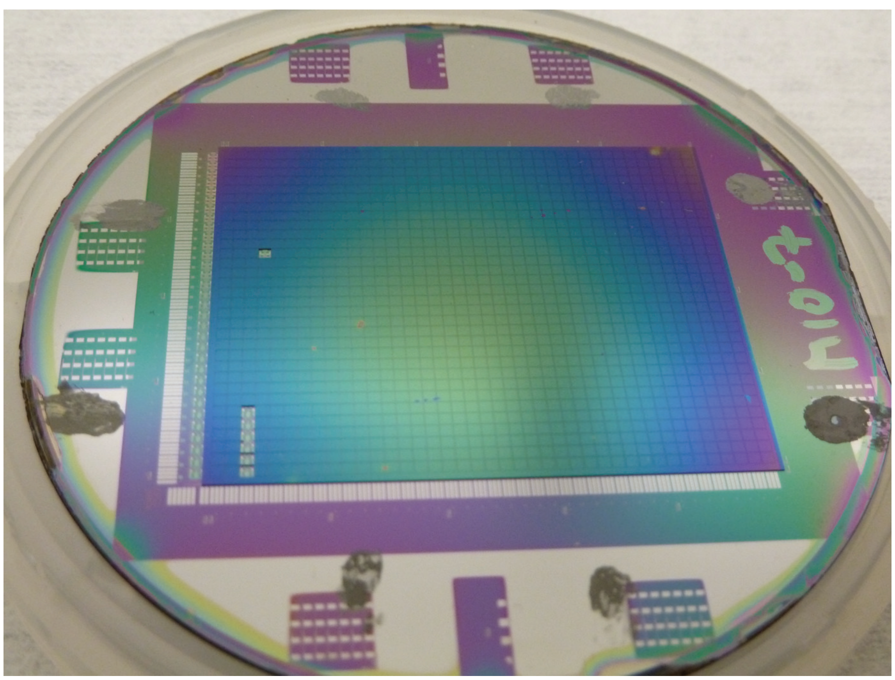


Figure 2. — Close-up photograph of an array that has just undergone laser dicing. Note that several bolometers have been removed (lower left) to eliminate shorts in the biasing circuit.

Array Installation and Instrument Re-commissioning

The arrays were finally completed and integrated into their new CEMs in May/June of this year. Even the shipping to Hawaii was not without problems, with one array in particular suffering some damage in transit. Having been inspected and double checked at the summit, a small team of JAC staff, along with Helen McGregor from the UK ATC, carried out the delicate installation work. Figure 4 shows the fully-assembled 850 μm focal plane in the clean room at the JCMT. The instrument was closed up and re-mounted on the telescope in September.

The re-commissioning of SCUBA-2 has been split into four distinct phases. Phase 1 concentrates on optimising the thermal environment, which includes establishing a good base temperature, enough cooling power to operate all arrays and adopting the best temperature control scheme. The majority of this work has now been completed. Phase 2, which (at time of writing) has just started, focuses on the arrays themselves, with the goal of establishing the most optimum set-up parameters and characterising both the multiplexer readout and the bolometers' performance. Unfortunately, this work has been somewhat hindered by continuing problems with the cryogenics, specifically the dilution refrigerator, that has forced upon us another warm-up and cool-down cycle. It is hoped that after the instrument is cooled again we will get a good picture of the array performance (at least as measured "in the dark"), ideally by Christmas. The third phase ensures that

(SCUBA-2 Array Upgrade, continued on page 12)

(SCUBA-2 Array Upgrade, continued from page 11)

all observing modes are functionally working and debugged. The final phase involves tests on the sky and will begin in the new year.

Reference

Holland, W., et al. 2006. *Proc. SPIE*, 6275, 45.

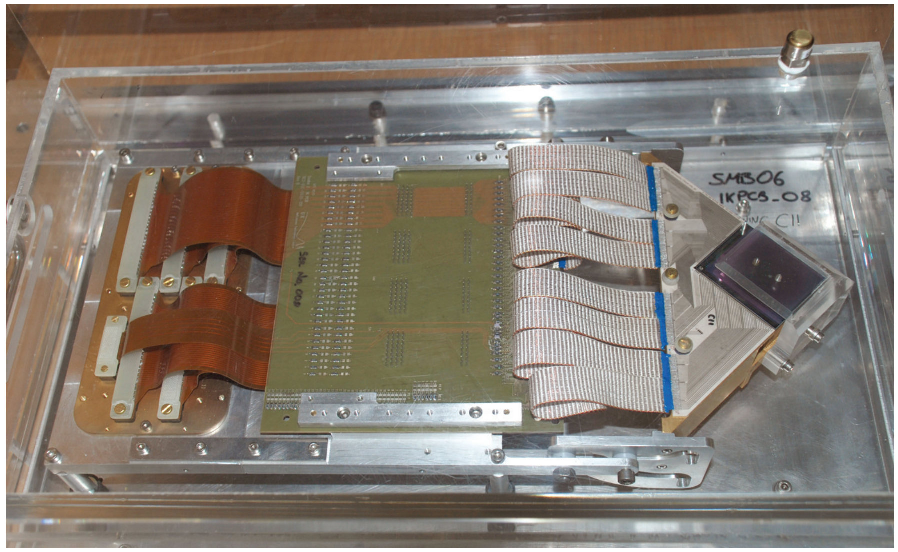


Figure 3. — Photograph of the cold electronics module with new phosphor-bronze coated niobium-titanium ribbon cables (towards the right of centre). The section in the middle will eventually contain the SQUID series array amplifiers (operating at 1 K).

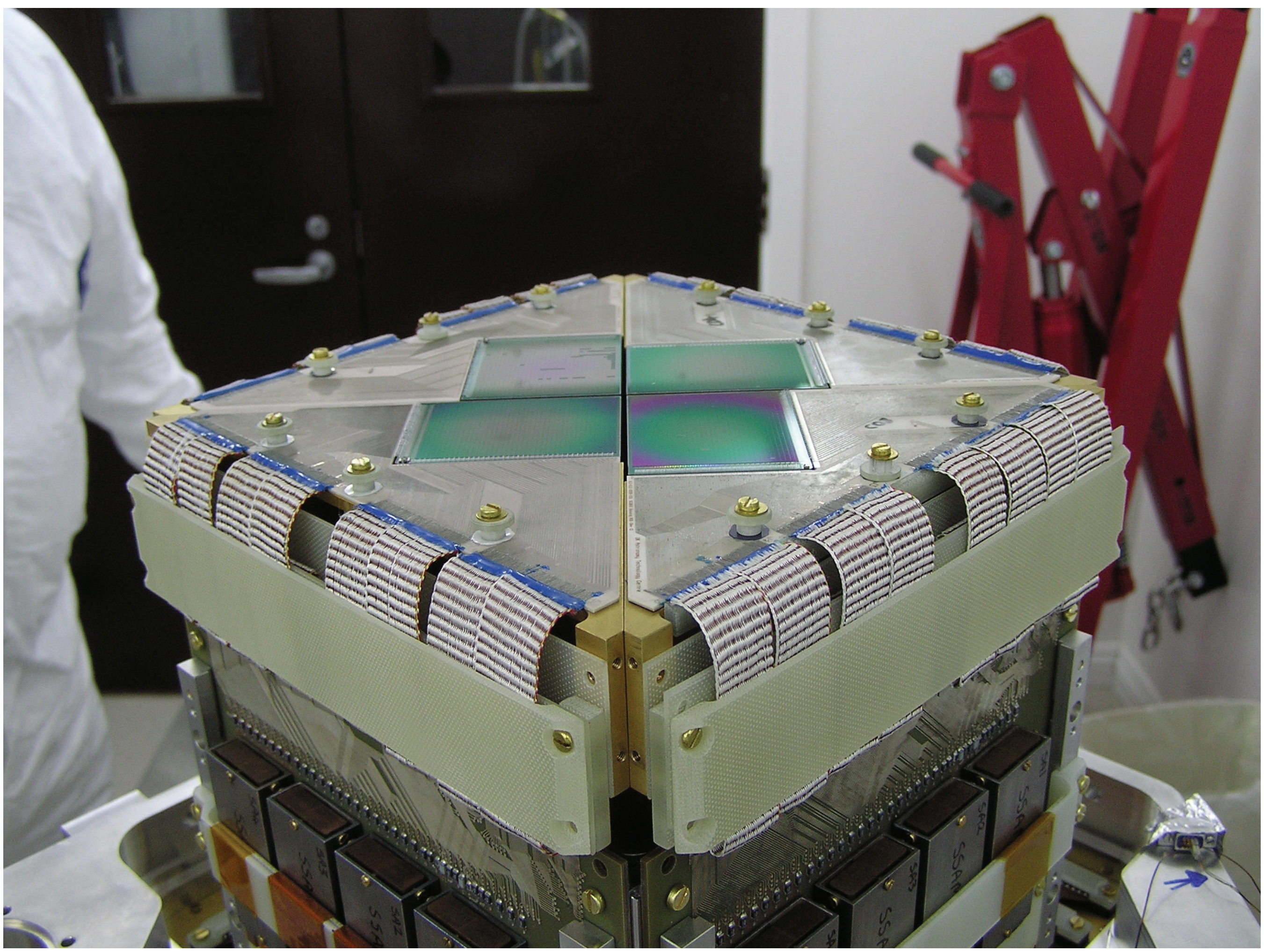


Figure 4. — Photograph of the fully-populated (and fully assembled) 850 μm focal plane.

El Niño Effect on Mauna Kea (Encore)

Remo Tilanus (*JCMT Head of Operations*)

When I reported on the weather statistics during this El Niño year for the previous *Newsletter* (Spring 2010), I had thought that El Niño had ended, since opacity had already declined from its grade 1 weather peak of February/March 2010. It turns out there is more to it. While grade 1 had indeed declined as expected, grade 2 has not. In fact, the weather has continued to be spectacular at a level not seen since the start of monitoring in 1989.

For the JCMT the 'weather,' *i.e.*, the water vapor content in the atmosphere above Mauna Kea as measured by the CSO 225-GHz tipper, is characterized by 5 grades, with grade 1 (opacity <0.05) being the best. The plots below show the percentage of nights per month in each grade[1]: the left plot shows the average since 1989, the right plot for this past year (October 2009 to September 2010).

The effect of El Niño on the observing conditions on Mauna Kea can be seen as a dramatic increase in the number of nights with the 'best' weather compared to the average during the period from January through March. While October 2009 was actually a worse than average month, by the time February and March rolled around there were double the number of grade 1 nights than on average. But from April onward, the number of grade 1 nights has been quite normal, considering the relatively large year-to-year variations typically seen.

The story is different for grade 2 weather though: not only has the number of nights been larger than average during the El Niño period from as early as November 2009, it has remained higher at a dramatically increased level throughout even September. As can be seen, while normally the level of grade 1+2 nights combined runs around 40%, this has been around 75% for the past eight months, except for a dip in June. This is quite unique over the past 20+ years of monitoring: periods of a few months (even August or September) with similar levels occur regularly, but not ones that last 8 months.

Not being an atmospheric scientist, I can only guess as to what might be the cause, but it is interesting to note that it has also been a below-average Pacific hurricane season with none coming even close to Hawaii to date. In fact, according to Wikipedia, it has been the least active September month since reliable record-keeping began in 1971. Prolonged periods of high levels of moisture over Mauna Kea generally result from one of two causes: an "upper level low" to the west of Hawaii pumping out a trail of moist air, or a south-west to north-east flow stalled over the islands bringing in warm and moist air from the equator. Neither of these happened this summer. In combination with the El Niño during the winter and spring, this may have given rise to the exceptional conditions seen this year.

Regardless of the cause, the excellent weather erased a back-log of high-frequency observations that have been in the queue for the past two years.

[1] The nightly weather grade is assigned based on the average opacity as measured by the CSO 225-GHz tipper over a 6 hr period between 9 pm and 3 am HST (between 7 and 13 UT).

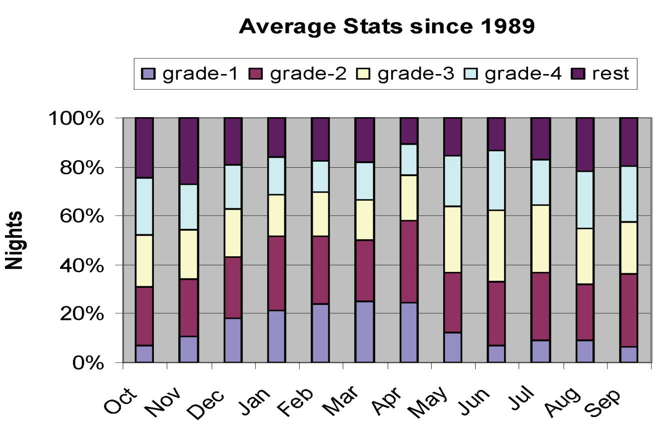


Figure 1. — Average monthly 225-GHz opacity Mauna Kea since 1989.

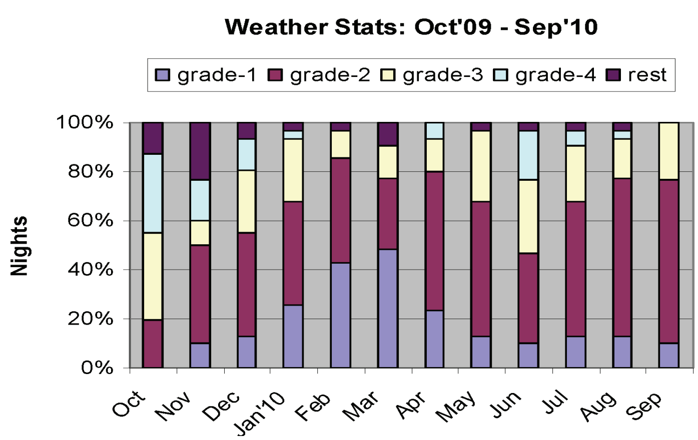


Figure 2. — Monthly 225-GHz opacity Mauna Kea for October 2009–September 2010.

Recent Improvements to the SCUBA-2 Iterative Map-Maker

Edward Chapin (*UBC–Vancouver*), David Berry (*JAC Software Group*), Andy Gibb (*UBC–Vancouver*), Tim Jenness (*JAC Software Group*), & Douglas Scott (*UBC–Vancouver*)

Introduction

Since the SCUBA-2 Shared-Risks Observing (S2SRO) period in early 2010, and thanks to users providing useful feedback, the SCUBA-2 data reduction team has made significant advances and we feel that we are now able to produce maps of publishable quality with SMURF (the Sub-Millimeter User Reduction Facility). While we have attempted to keep the user community up-to-date through our blog, the large number of updates in recent months may have been difficult to follow for casual or new users of the software. In this article we summarise some of the more significant improvements.

Large-Scale Structure

The underlying difficulty in producing maps from SCUBA-2 data is drift in the bolometers. The bulk of this drift is common to all of the bolometers, and is dominated by variations in the fridge temperature (roughly periodic with a ~25 sec period, but also with significant higher-frequency components), and by atmospheric variations. However, once the average signal from all of the detectors has been removed, there are still significant residual drifts that are independent of one another.

The time scale on which these residual drifts are significant, compared to the white (thermal) noise levels in the bolometers, is usually around 1 sec ($1/f$ knee of 1 Hz) for the 850 μm array, and a few seconds for the 450 μm array ($1/f$ knee of 0.2 to 0.5 Hz). While we have experimented with numerous methods for modelling and removing these residual low-frequency noise components, we have obtained the best (and most consistent) results using a simple high-pass filter.

Therefore, in its simplest form, the SMURF algorithm: (i) fits and removes the average common-mode signal from each time series; (ii) high-pass filters the data; (iii) regrids the residual signal to produce a map; (iv) removes the effect of astronomical signals in the current map estimate from the bolometer time series; and, (v) repeats back to (i) replacing each signal component (common-mode, residual low-frequency noise, astronomical signal) in turn before re-calculating them. This procedure is iterated until the residual signal stops changing appreciably.

The problem with this iterative algo-

(SCUBA-2 Map-Maker, continued on page 15)

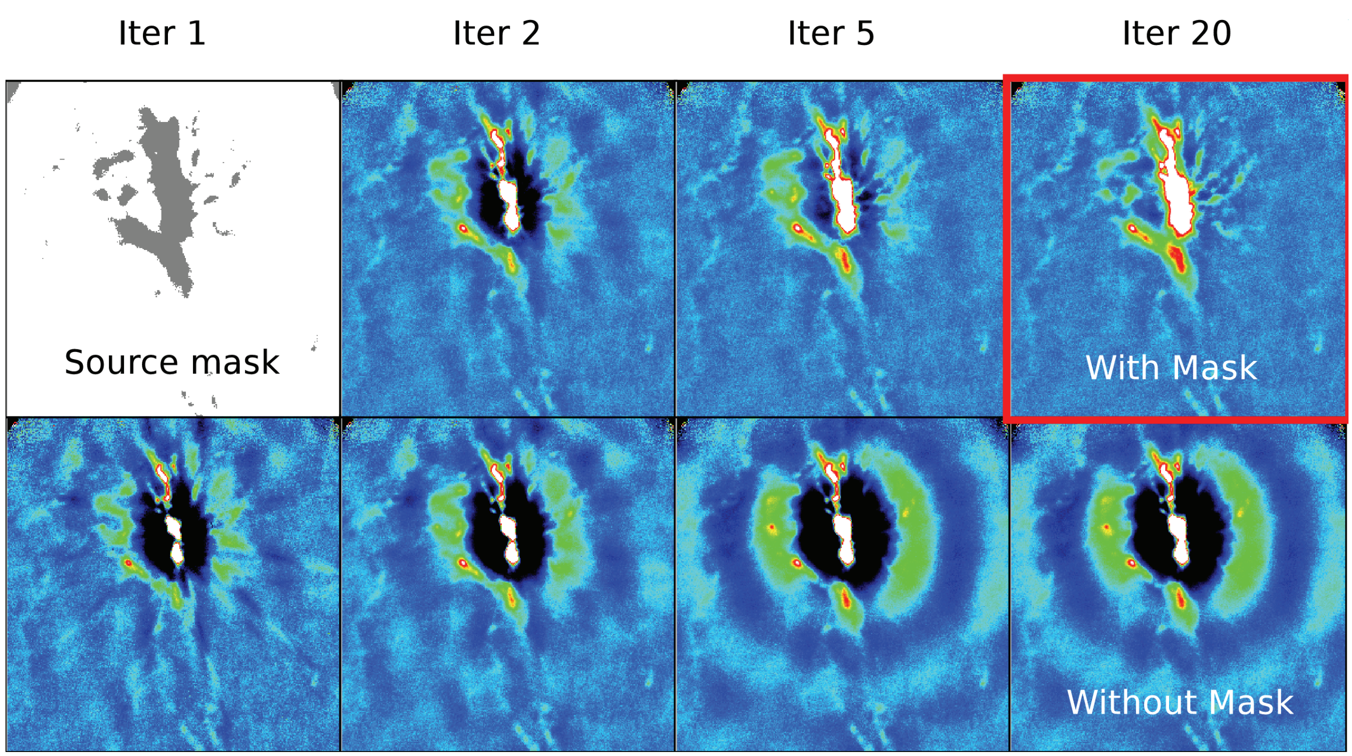


Figure 1. — Two reductions of OMC-1 using 20 iterations. In the top row a S/N mask has been used to constrain fainter regions to zero (although the images show the maps immediately before applying the constraint) until the final iteration. The mask is refined after each iteration, but only the final mask is shown in the top-left corner. The bottom row shows the result without any constraints, indicating the degeneracy (ripples) between large-scale structures and the low-frequency noise removed from the bolometer time series. The initial iteration (bottom-left) is identical in each case.

(SCUBA-2 Map-Maker, continued from page 14)
rithm is that large-scale structures in the map cannot be distinguished from the low-frequency noise that is removed in the common-mode rejection and high-pass filtering steps. The characteristic scale of this degeneracy is of the order of the array footprint (about 2 arcmin) for the common-mode, and the scan velocity divided by the $1/f$ knee frequency for the high-pass filtering. In early reductions of the S2SRO data, this degeneracy would typically produce large-scale undulations in the map. While these structures could be suppressed with harsh 2-D spatial filtering for point-source studies, it was virtually impossible to make useful maps of more extended sources.

To combat this problem, we have added a system for constraining regions of low-S/N to be flat after each map estimate, while allowing high-S/N regions to vary. This constraint is then relaxed on the final iteration so that even the faint areas of the map can contain sources (although they have been effectively filtered on the scale of the array footprint). The results have been extremely encouraging: in Figure 1 we compare two reductions of the same Orion Molecular Cloud (OMC-1) map using 20 iterations, both with and without the S/N mask.

(SCUBA-2 Map-Maker, continued on page 16)

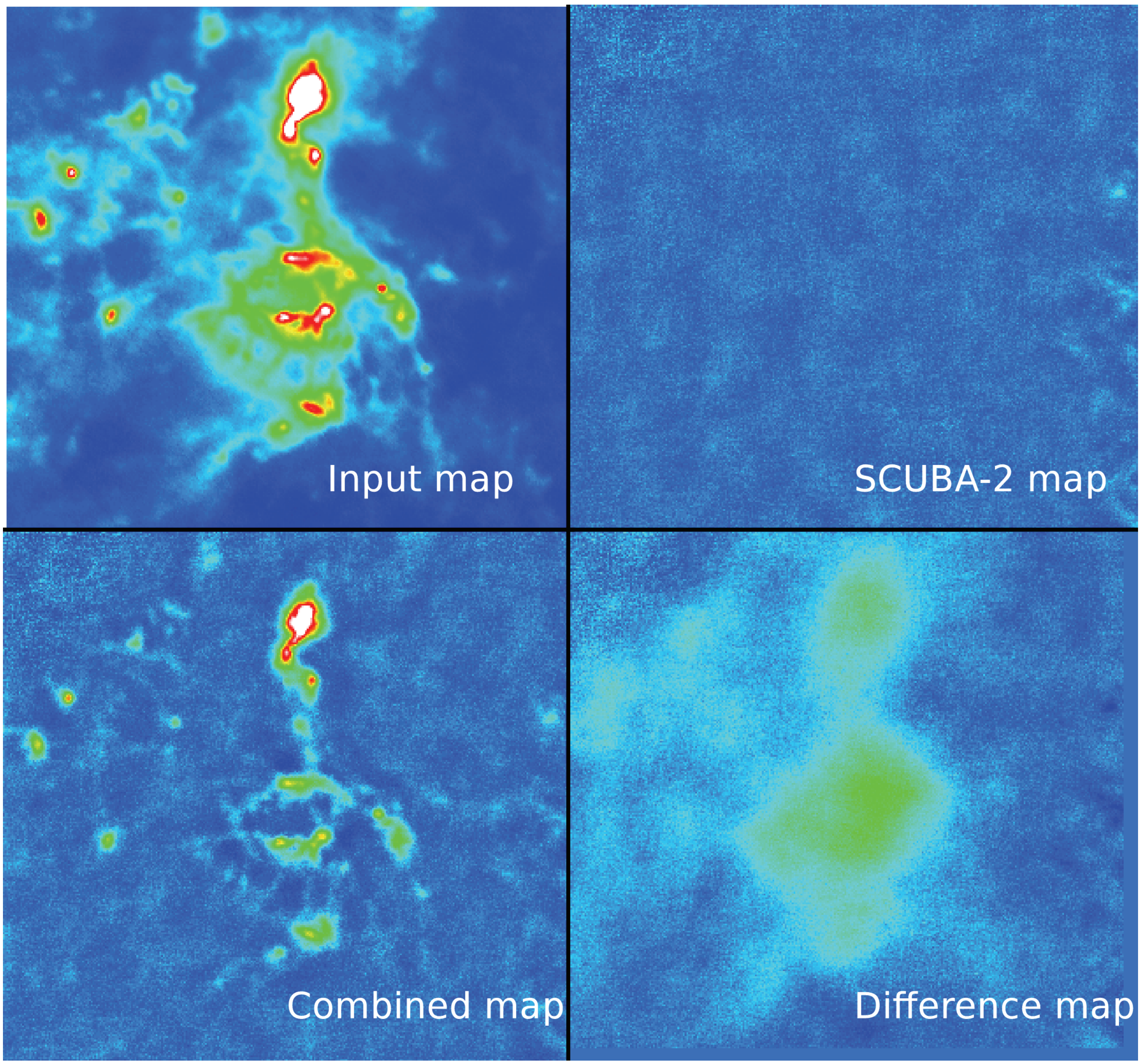


Figure 2. — To test the impact of map-making on a known source, we have added the signal from a map of Vela at 350 μm taken with the Balloon-Borne Large-Aperture Submillimeter Telescope (top-left) to real 450 μm SCUBA-2 data (top-right). The resulting map produced by SMURF (bottom-left) has had some of the large-scale information removed, which is readily seen in the difference between the input and combined maps (bottom-right).

(SCUBA-2 Map-Maker, continued from page 15)

There are now three styles of masking available: (i) the iterative S/N cut (useful for bright extended structures); (ii) circular regions (useful for compact sources at known positions); and, (iii) hits threshold (effectively setting the edges to zero). These masks have been incorporated into the reductions performed by the JCMT Science Archive (JSA).

Related to this, we have also introduced a more intuitive system for specifying the high-pass filter edge. In the past, only a temporal frequency could be specified; it would then be up to the user to establish (based on scan velocity), what angular scale on the map this would correspond to. It is now possible to instead specify an angular scale, and SMURF will internally convert that quantity to a frequency. In this way it is possible to reduce multiple maps of the same region, potentially taken with different scan velocities, while ensuring that the response to large angular scales will be the same in each map.

Map-Based De-Spiking

While great strides have been made towards automatically remedying data glitches, such as spikes and abrupt DC level changes in the bolometer time series, inevitably some fraction of them always get through to the final map. These features result in obvious spikes in the map, and sometimes streaks that follow the scan-pattern. We have added a "map-based" de-spiker which has worked extremely well at identifying and removing these remaining features.

Since each pixel in the map contains many samples (from different bolometers, and at different times), we simply identify the outliers from these input samples and reject them. Unlike time-domain de-spikers which have difficulty distinguishing genuine glitches from bright, compact sources, transients will *not* tend to occur repeatedly at the same location on the sky, and are therefore easily identifiable. This additional step has enabled us to produce smooth-looking maps of even the most pathological data sets without needing to resort to manual data flagging.

Adding Simulated Sources to Real Data

Given the amount of filtering required to produce maps of SCUBA-2 data, it is essential to characterize the attenuation of known input sources. While a simulator has been available as part of SMURF since its inception, there has never been an easy way to generate synthetic data scanned in exactly the same way as a real observation. We have now added a facility for adding signal from an external map to existing bolometer data. The addition is performed *before* data cleaning, so the effects of synthesized sources can be used to test the entire process.

In Figure 2 we show an example in which signal from a Balloon-Borne Large-Aperture Submillimeter Telescope map of Vela at 350 μm (see http://blastexperiment.info/) has been scaled to a signal range similar to OMC-1 at 450 μm, and added to a region of real 450 μm SCUBA-2 data that is nearly devoid of sources. We then produce a map from the resulting data, and difference the original BLAST map with the output of SMURF revealing the large-scale structure that has been suppressed.

Down-Sampling

Have you ever been stuck in an airport and wanted to reduce some SCUBA-2 maps on your single-core laptop with 4 GB of memory? Previously this would have been an extremely frustrating experience (or completely impossible) because of the volume of 200 Hz sampled SCUBA-2 data. This fast sample rate was chosen so that it would be possible to scan the telescope up to 600 arcsec/sec to cover large areas, while fully-sampling the 8 arcsec 450 μm beam. However, most S2SRO data is scanned between 120 and 240 arcsec/sec, meaning that the data need only be sampled at a fraction of that rate in many cases. We have added the capability of down-sampling SCUBA-2 data on-the-fly, reducing the memory footprint and execution time. Even if this feature is not turned on for your final science-grade image, it will certainly allow you to play with the data more than you might have otherwise (even on your laptop).

The Future

In the coming months, as the SCUBA-2 upgrades are completed, we will continue to explore further improvements that should enable the reconstruction of larger-scale features in the maps. For updates, continue to watch the blog (http://pipelinesandarchives.blogspot.com/), and also feel free to send questions and comments to our e-mail list, scuba2dr@phas.ubc.ca .

Arrivals and Departures

Chris Davis (*JCMT/UKIRT Senior Support Scientist*)

Its been a rather unusual year at JAC, as rumours from the funding agencies and particularly STFC trickle through to Hawaii, and the impact of the financial belt-tightening in the UK takes its toll locally. Of course its also been a busy and very exciting year, as early results from SCUBA-2 Shared-Risks Observing (S2SRO) become available and recommissioning work continues apace. Here I review some of the staff movements that have occurred at JCMT during this period.

Sam Hart will be leaving the JAC software group in early 2011. Sam has been responsible for (among other things) the JCMT Observing Tool and Northstar, the proposal preparation and submission software in use at both UKIRT and JCMT. Luca Rizzi has transferred internally from UKIRT to work within the group. Luca was until recently employed at UKIRT as a Support Scientist and as UKIDSS Survey Scientist. Given the other departures alluded to in the last *JCMT Newsletter* by the Director (Walther Zwart and Brad Cavanagh), it looks like he will have many fine pairs of shoes to fill!

Marcel Tognetti has also left us recently, moving over to Gemini after more than three years of service as an Electronics Instrument Technician.

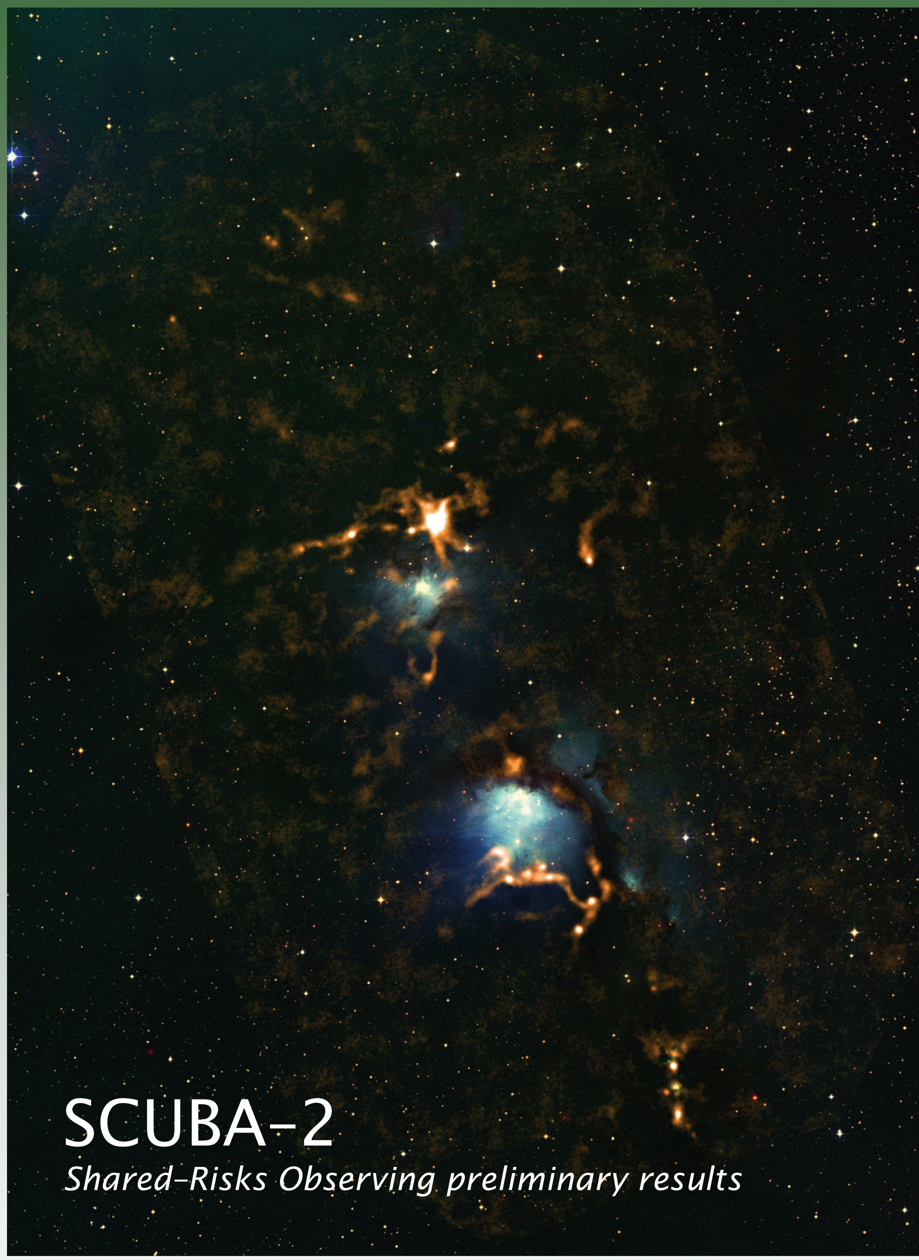
As noted in the *UKIRT Newsletter*, a result of the move to minimalist mode at UKIRT has been the need for a number of very regrettable redundancies. These include James Webb, who returns to Australia with his family after a year at JAC in the engineering department; Connie Larsen, who has been working as a receptionist at JAC for the last few years; Inge Heyer, our Public Information Officer since early 2006; and Anna Lucas, who has been the UKIRT Secretary for an amazing three decades (see the *UKIRT Newsletter* for more details).

Frossie Economou, an integral part of the software group for over 15 years, will also be leaving JAC in the coming months. Frossie has been a driving force behind numerous projects at both UKIRT and JCMT, not least the OMP and flexible scheduling! She has been the project manager and inspiration for the JCMT Science Archive (JSA), from it's inception as the ORAC-DR pipeline to the sophisticated archive and science repository that we have today. She was instrumental in bringing together a functional (and I'm told enjoyable!) collaboration with the archive team at CADC that has made the JSA possible — a project that will ultimately ensure the legacy value of JCMT. More recently, she has been heavily involved in the processing of S2SRO data in conjunction with the University of British Columbia.

Firmin Oliveira will also unfortunately be leaving JAC after a remarkable 21 years of service. Firmin has contributed in numerous ways to the development of the JCMT; he has been responsible for several of the JCMT instruments, most notably RxA and RxW, and recently converted the instrument software to run on Linux, thus helping us move software off of the VAX. Lately he has been involved in the testing and commissioning of ROVER, FTS-2, and polarimetry with SCUBA-2. He has also provided considerable support to Remo when eSMA observations were in progress. Firmin is also recognised locally as a great Slack Key guitar player. He has performed at many a staff get-together and has released a CD of his own music, entitled *Hana No Ka Oi*.

We would like to extend our best wishes to all who have left (or are about to leave) the JAC, and hope that they find good fortune in all of their future endeavours. As Bob Dylan would say, "the times they are a-changing'." Or was that Buddy Holly?

Figure 1. — Firmin Oliveira's Hana No Ka Oi album.



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