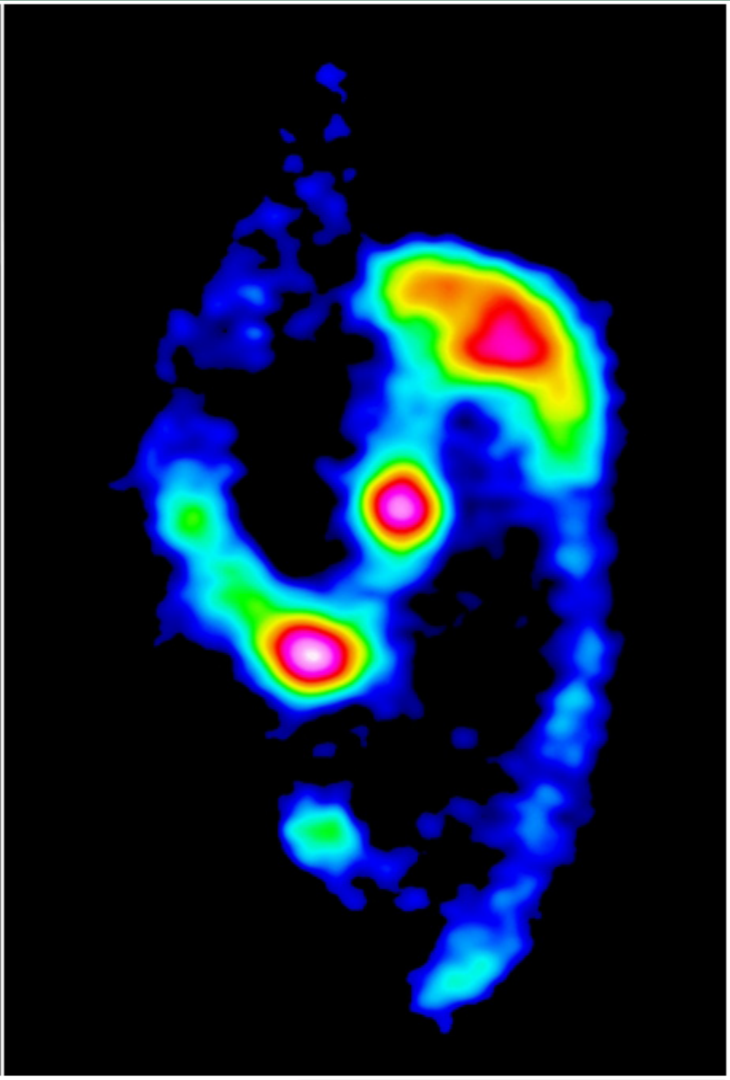
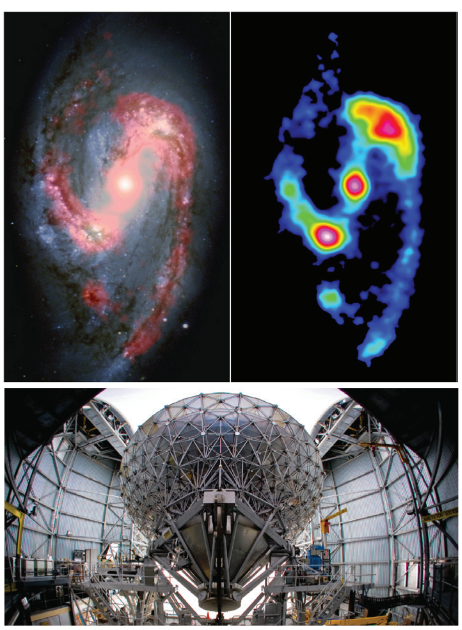
JCMT Newsletter

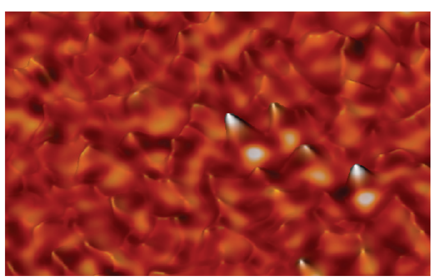
James Clerk Maxwell Telescope



www.jach.hawaii.edu/JCMT

#34 January 2013





▲ BACK COVER: SCUBA-2 450 μm map of the UKIDSS-UDS/CANDELS field from the S2CLS (see page 6). The map has been visualised in 3D relief form, using the signal-to-noise ratio as the elevation.

◀ FRONT COVER: (Top left) A composite image of M66: the red colours show the galaxy as it appears at 850 μm, while the white background shows visible light. (Top right) The SCUBA-2 image at 850 μm on its own. See the NGLS article on page 8 for more information. (Bottom) A rear view of the JCMT dish.

The Joint Astronomy Centre (JAC) 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 Organisation for Scientific Research (NWO). It is overseen by the JCMT Board.

James Clerk Maxwell Telescope
Joint Astronomy Centre
University Park
660 N. A'ohōkū Place
Hilo, HI 96720-2700
USA

Tel: (808) 961-3756

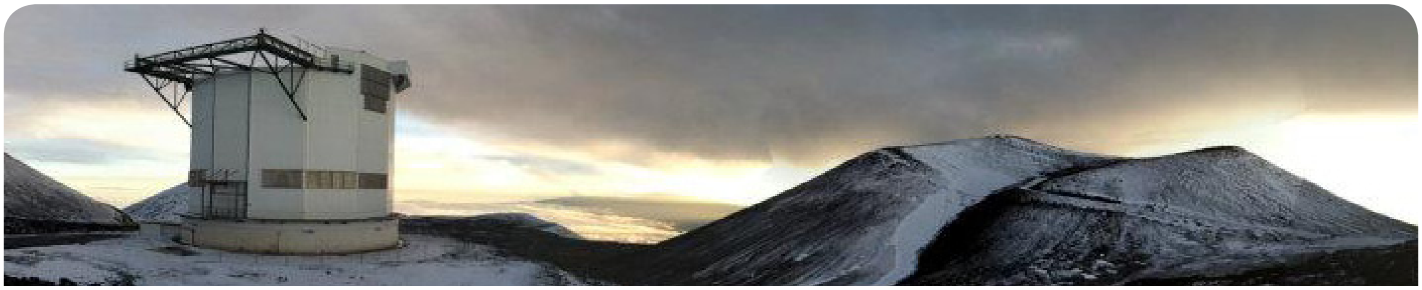
Fax: (808) 961-6516

web: www.jach.hawaii.edu/JCMT

ISSN 1351-5497.

The JCMT Newsletter, James Clerk Maxwell Telescope, is edited by Holly Thomas.

From the Desk of the Director



Professor Gary Davis, Director JAC

I am typing this in my office on a Saturday morning at 07:30. Outside, a maintenance crew is cutting the grass around the JAC. The sky is clear but the wind is (unusually) from the west, and the town of Hilo is enveloped by a thick cocoon of volcanic haze known locally as 'vog'. The sunrise this morning was brilliant, with bright red and yellow colours as the light fought its way through the layers of haze. I can just make out the telescopes on the summit through the reduced visibility. It is all very surreal.

I am not often given to descriptive prose, but the events of the past year have put me in a contemplative mood. Most readers will be aware that, since the previous newsletter, the three agencies that support the operation of the JCMT have all decided to withdraw their funding. There is quite a lot I could say about this but I will keep the story short. Consistent with their long-term strategy for the past decade, NWO will leave the JCMT partnership on 31st March 2013 in order to re-direct funds to their regional ALMA support node, called ALLEGRO. From that date onwards, STFC will cover NWO's 20 % funding share and the UK's share of PI time will increase from 55 % to 75 %. A similar situation applies in Canada, where it has long been recognised (starting with the first Long Range Plan in 2000) that withdrawal from the JCMT was a price to be paid for joining ALMA; accordingly, NRC have decided to leave the JCMT partnership on 30th September 2014. The withdrawal of both partners left the UK agency STFC in a challenging position, and following a review process in early 2012 they decided that, despite the compelling science case and the £15.7M investment in SCUBA-2, they were unwilling to take the risk of finding themselves the sole operator of the telescope. Consequently, STFC funding for JCMT operations will cease on the date of the Canadian withdrawal, 30th September 2014. Needless to say, this outcome has been very difficult for everyone associated with the observatory, but I have been impressed beyond words by the professionalism of the JAC staff who remain fully committed and dedicated to their work in support of both UKIRT and the JCMT.

In the previous newsletter (Autumn 2010), I wrote that SCUBA-2 had been delivered and successfully cooled to operating temperature in preparation for commissioning. After much hard work over the following year, the instrument was successfully commissioned and released for community science observing on 30th September 2011.

I want to pay particular tribute to the JAC staff at this point. Conventionally, when a new instrument is delivered to the JCMT, a commissioning team comes out to Hawaii to commission the instrument on the telescope and to train local staff in its operation and maintenance. On this occasion, for a variety of reasons that are no longer germane, that didn't happen and we had to commission the instrument ourselves. This was extremely challenging for everyone concerned: the JAC is staffed to support operating instruments, not to commission complex instrumentation built by someone else — that requires an entirely different mix of skills. Everyone at the JAC pitched in to this truly Herculean and ultimately successful effort, and in gratitude for this work performed under exceedingly difficult circumstances, the Board awarded 30 hours of observing time to the JCMT science staff. This is unprecedented in my experience.

SCUBA-2 is working extremely well and our users are generally happy with their data: this issue of the Newsletter contains several science articles, primarily from the JCMT Legacy Survey teams, providing a tantalising glimpse of what is to come over the next couple of years. Nevertheless, those of us who are close to it know that the instrument isn't performing as well as it should: the dark noise is roughly a factor of two higher than expected (based on measurements of the fundamental parameters of the detectors), and the noise is variable with time for reasons we do not yet understand. We are working through these issues with the instrumentation experts. If we can identify a means of remediating these issues and recovering some performance, we will certainly do so if at all possible: our prime directive at this point is to generate the maximum possible scientific impact in the time that remains under the current partnership.

With that in mind, the JCMT Legacy Survey was rescoped in late 2011 and early 2012. The objectives of this exercise were (a) to take full account of the performance of SCUBA-2 as it was then understood, and (b) to design a science programme for the JCMT that would optimise its scientific impact over the period to 30th September 2014 (at that point the date of Canadian withdrawal was known). The Board set up a dedicated panel for this purpose, the JCMT Legacy Survey Redefinition Group (JLSRG), and the final programme was approved at a special Board meeting on 30th January.

This process involved some drastic reductions in the scope of the JLS projects — in their report to the Board, the JLSRG described this process as "painful" because a lot of excellent science had to be dropped from the programme for lack of time. At the same time, the JLSRG also recommended that 35% of the telescope time be reserved for PI science in order to maintain scientific diversity and to keep the community engaged: since SCUBA-2 was released, PI time in the UK and Canada has been oversubscribed by factors exceeding 4 (in semester 12B, Canadian time was oversubscribed by more than a factor of 8!). With this process complete, the observatory's science programme up to 30th September 2014 is now fixed.

So what of the future? The first thing to bear in mind is that nobody has yet decided to close the telescope: the only decision that has been made is that the three agencies have decided to cease funding its operation. The site on Mauna Kea is leased from the University of Hawaii (UH), and the lease specifies the options that are available to us when operations cease: (a) transfer it to UH, (b) transfer it to a third party, subject to UH approval, and failing those (c) decommission the telescope and restore the site.

At the moment I am working through all of these options. In early 2013, I will issue an Announcement of Opportunity for entities interested in participating in the JCMT beyond September 2014, following the same process that is already underway for UKIRT. The observatory will be made available at no acquisition cost, and STFC will provide funds to the new owner to cover the liability associated with decommissioning and site restoration. This is the deal of the century for any entity willing to take over the world's premier single-dish sub-millimetre observatory. As I have said before, if the UK and Canadian communities wish to retain access to the JCMT beyond September 2014, the best thing you can do is position yourselves to respond to that announcement.

As noted elsewhere in this Newsletter, staff turnover at the JAC has been very high. Since the funding announcement came down we have lost some senior staff with years of experience that will be impossible to replace: Antonio Chrysostomou, Tim Jenness and Remo Tilanus will be known to many of you, but there are others who are perhaps less well known in the science community but who have also been critical to the JAC's success. Simon Craig, Chief Engineer, and John Kuroda, SCUBA-2 support technician, are examples. We are recruiting to fill all of these vacancies and whilst this will not be easy, I am pleased to report that Dr Doug Johnstone has joined the JAC on secondment from NRC. Doug is the new Associate Director, replacing Antonio, and will be well known to many in the community, not just in his own area of star formation. In the few weeks he has been with us he has invigorated the JCMT science group and I am absolutely delighted to have him on board. I just hope he doesn't mind the vog.

From the Associate Director

Doug Johnstone (Associate Director JCMT)

Aloha from Hilo. This is my first time contributing to the JCMT Newsletter as the Associate Director, although I have in the past been involved with Newsletter science articles. I have been at the JAC for only two months and yet already it has been an incredible learning experience as to how the telescope operates from the 'inside'. My most important observation to date has been the quality and capability of the staff. Their dedication and wisdom have very much helped me transition into this new role and I have found the friendly, family-like, atmosphere at the JAC wonderfully supportive. We have much work to do: maximizing the scientific impact of the telescope over the next three semesters, promoting the capabilities of the telescope to potential new owners, and dealing with the stress of an uncertain future. That said, I could not have hoped for a better group of individuals with whom to undertake this journey.

The entire JCMT staff continue to work diligently on all of our behalf supporting PI and Legacy Survey observers, maintaining and characterizing the critical instruments, and testing, debugging, and advancing the data reduction techniques, especially for the SCUBA-2 map-maker. Interaction with the JCMT user community is extremely important for the staff. Such opportunities allow them to better understand the time-critical needs of the community and provide them with the chance to express their technical, and research, credentials. If you are headed to Hawaii to observe at the JCMT or another telescope, please consider stopping by the JAC in Hilo for a few days to interact with the staff. For those with specific research connections there may even be some funds available to support your stay while at the JAC (drop me, or a staff member, an email).

The JCMT Legacy Surveys (JLS) are now well underway, although some have had greater weather success than others. Write-ups on all seven surveys appear in this Newsletter. I had very helpful discussions with each of the survey coordinator teams in the Autumn and it is clear that the largest concern remains completion of the observations by September 2014. I will be working with the JCMT staff and the survey teams over the next few months to understand what measures might be taken to mitigate this issue. Now is the time to think outside the box!

During Semester 13A we will be working with the external instrument teams to fully commission POL-2 and FTS-2. Both of these ancillary instruments had PI shared-risk observations awarded by the ITAC. In house, we plan to complete the upgrade of RxA, in part to support VLBI efforts. We are also monitoring the noise properties of SCUBA-2 in hopes of increasing the instrument's efficiency, and working hard on enhanced data reduction techniques for both SCUBA-2 and HARP. Further, the JCMT Science Archive (JSA) at the CADC is beginning an upgrade to support those legacy products most important to the JLS, providing a lasting heritage for the telescope well beyond 2014. Additionally, all former GSD-formatted DAS data are being converted to ACSIS format and will be ingested into the JSA, enhancing the JCMT's heterodyne legacy.

Looking forward to semester 13B, it is worth noting that this will be the last full Autumn semester under the current partnership. Together with members of the ITAC, we are considering whether any changes to the Call for Proposals or the proposal ranking process should take place given this unique situation. Please read the Call for Proposals carefully when it is released in mid-February. Most importantly, however, if there is an observation in the Autumn sky that you are keen to observe, 13B is the time to propose!

For those daunted by the prospect of reducing SCUBA-2 observations, a data reduction cookbook has been written by Holly Thomas and can be found on the JCMT web-page (for more details, see her article in this Newsletter). Three papers that describe SCUBA-2 and how it works on the JCMT have been accepted for publication in MNRAS and are available on astro-ph: Holland et al. (arXiv:1301.3650) describes SCUBA-2, Chapin et al. (arXiv:1301.3652) describes the SMURF map-maker, and Dempsey et al. (arXiv:1301.3773) describes instrumental calibration. These publications should be referred to when publishing SCUBA-2 data.

The future of the JCMT remains uncertain (see Director's Message). We are actively promoting the importance of the JCMT beyond September 2014 and will continue to do so next year. I took a poster on the importance of the JCMT in an ALMA world to the ALMA First Results meeting in Chile which can easily be modified by others looking to 'sell' JCMT science opportunities (http://www.astro.uvic.ca/~johnston/JCMT/ — thanks to Harriet Parsons for creating the poster).

Finally, on an extremely positive note, 2012 was another excellent year for JCMT publications (see Newsletter article). Many of the papers are still focussing on legacy SCUBA observations, reiterating the critical importance of a comprehensive and navigable archive. We look forward to an increasing number of SCUBA-2 publications in 2013. The near term science impact of the JCMT continues to look impressive.

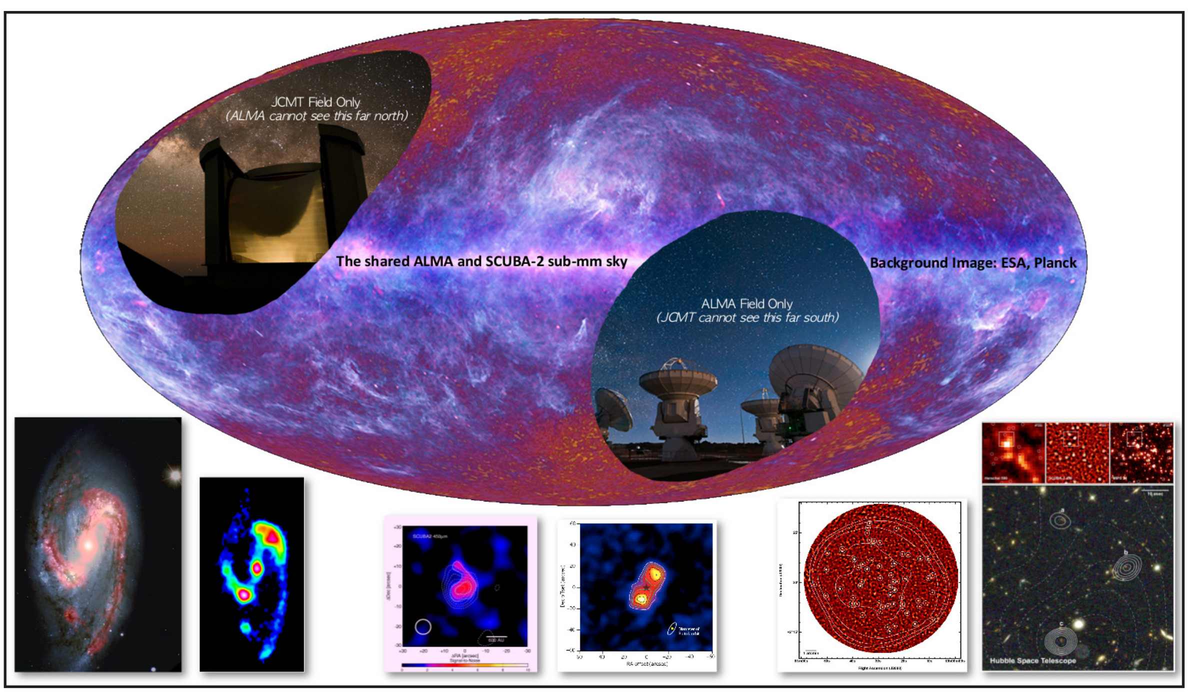


Image taken from a poster presented at the 'First Year of ALMA Science' conference held in December 2012. The main image shows the sky visible from both ALMA and the JCMT; it emphasises the substantial overlap despite their different latitudes.

The insets below highlight science results from surveys already in progress. These results are elaborated on in this Newsletter.

S2CLS: First Results

James Geach (McGill University, CA) on behalf of the S2CLS consortium

From SHADES to S2CLS

It is approaching a decade since the first SCUBA Half-Degree Extragalactic Survey (SHADES) commenced (Coppin et al. 2006; see also JCMT Newsletter #27), a survey that aimed to detect a handful of distant ultra-luminous galaxies over half a square degree of sky to an rms depth of 2 mJy at 850 μm. The retirement of the SCUBA instrument in 2005 curtailed SHADES, resulting in only 50 % of the area mapped (split over two well-studied fields).

In 2010 we took the next step forward in our exploration of the submillimetre Universe, with the start of observations for the JCMT SCUBA-2 Cosmology Legacy Survey (S2CLS), drawing upon the power of the revolutionary new SCUBA-2 camera, with its vastly superior mapping power and sensitivity in the 450 μm and 850 μm bands. The goal of the S2CLS, the largest of the seven JCMT Legacy Surveys, is simple: it will provide the first samples of thousands of extragalactic sources selected in the 450 and 850 μm wavebands. These atmospheric windows allow us to access the redshifted far-infrared emission from luminous, but highly obscured, high-redshift galaxies and AGN, pin-pointing an era of intense activity in the early Universe associated with the formation of massive galaxies and the black holes that inhabit them.

Observing Strategy

S2CLS has a simple two-tier design, comprising a wide 850 μm and deep 450 μm survey over a smaller (overlapping) region. The target regions are located in a set of well-defined fields with appropriately low far-infrared backgrounds, and supporting multi-frequency data for the detailed study of the submillimetre galaxy (SMG) population.

The current survey plan is to map an area of 10 deg^2 to a 850 μm depth of $1\sigma = 1.5$ mJy and 0.25 deg^2 to a 450 μm depth of $1\sigma = 1.2$ mJy. To achieve this, we are mapping several well-studied extragalactic survey fields (including the original SHADES fields) for which a wide range of ancillary data from years of observational investment (from nearly every major astronomical facility, both terrestrial and extra-terrestrial) has been made. The contribution of deep SCUBA-2 mapping now being provided by S2CLS is a valuable addition to this legacy.

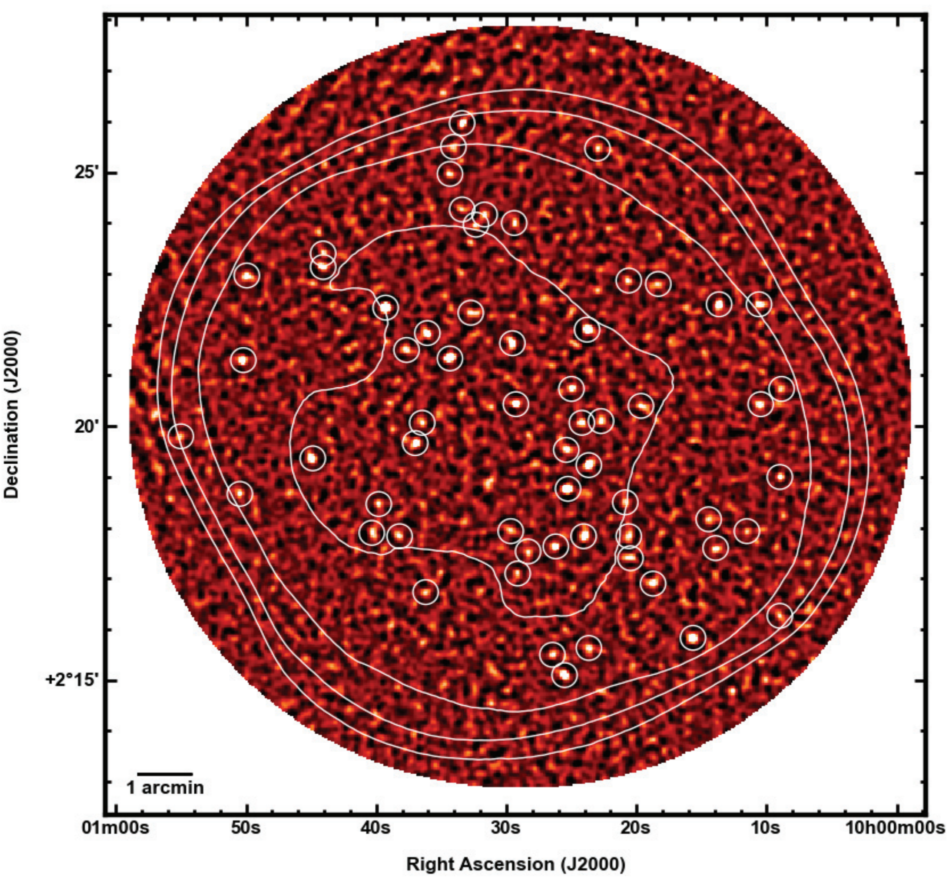


Figure 1: SCUBA-2 450 μm map of the COSMOS field, reaching a depth of 1.5 mJy. The circles highlight several distinct submillimetre sources.

Science Goals

The main driver for the wide 850 μm part of the survey is the need to deliver a sample of a sufficient number of galaxies to reliably measure the clustering of the submillimetre population (providing valuable constraints on galaxy formation models) and to detect and study the (rare) progenitors of rich clusters. The 850 μm survey will also establish, unambiguously, the faint end of the counts of SMGs in this band.

The goal of the deep 450 μm component of the survey is to obtain the first confusion-limited imaging at 450 μm (expected to correspond to an rms noise of ~1 mJy). This will enable us to resolve a large fraction of the extragalactic background light at 450 μm into individual galaxies, as well as provide precise positions that will allow us to identify the 'counterparts' of these sources in other wavebands and assess the size of the submillimetre-emitting regions. In parallel with these deep observations we will also obtain extremely deep 850 μm observations of these regions which will provide both high-quality submillimetre colours for the 450 μm sources and information about the very faint 850 μm population.

This single co-ordinated survey programme will revolutionise our understanding of submillimetre galaxies, and indeed galaxy formation in general, with enormous and lasting legacy value, as well as provide a springboard for future exploitation of the latest and next-generation facilities — Atacama Large Millimetre Array, Herschel, LOFAR, James Webb Space Telescope and the Square Kilometre Array. At the time of writing, the S2CLS has acquired 283 hours of on-sky integration, out of a total allocation of 1778 hours. We have already mapped a total area equivalent to 12 times the total area of SHADES.

First Results

Early science results have focused on a 450 μm map of the COSMOS field — a 50 hour DAISY integration executed in prime [τ(225 GHz) < 0.05] conditions. The map covers a 140 arcmin^2 region overlapping the HST CANDELS legacy field (Grogin et al. 2011), and reaches an rms depth of 1.3 mJy at 450 μm.

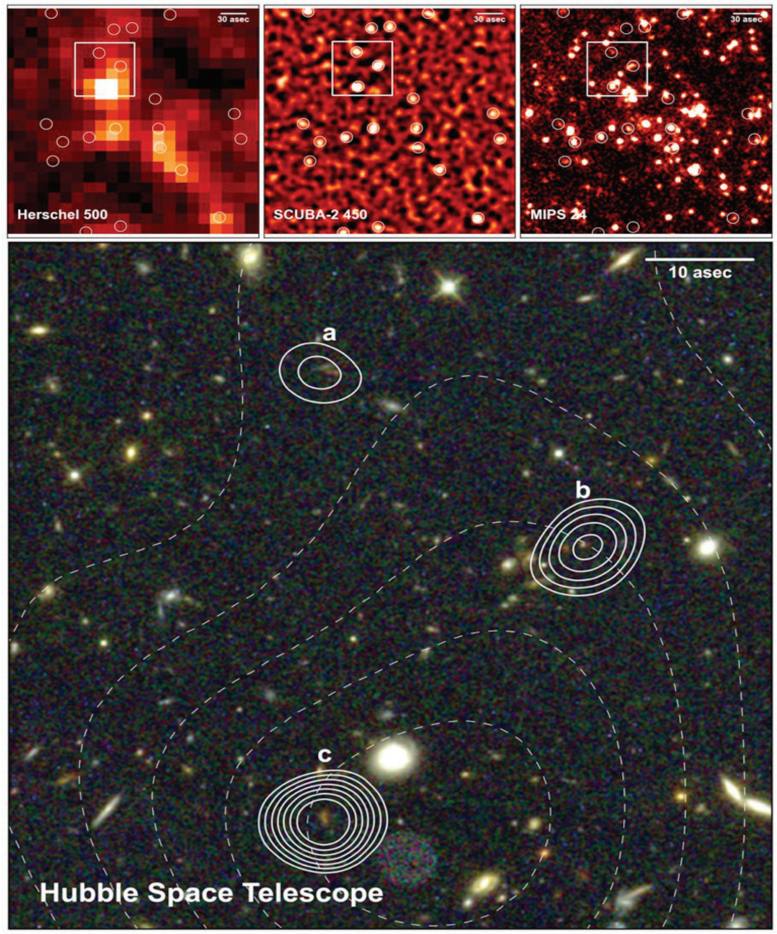


Figure 2: The main panel shows a HST field with 3 contoured sources. This field is shown in the panels at the top (white boxes) in Herschel 500 μm, SCUBA-2 450 μm and MIPS 24 μm respectively. Credit: HST/Herschel/JCMT/Spitzer.

Using the deep COSMOS map, which represents the deepest blank-field 450 μm map to date (see Figure 1), we have measured the number counts of sixty robustly-detected 450 μm–selected galaxies and their contribution to the cosmic far-infrared background (CFIRB) for the first time (Geach et al. 2012, submitted). The new catalogue of 450 μm-emitters provides the most accurate measurement of the counts of these galaxies to date, and we have used it to measure the number counts of extragalactic sources in a flux regime probing far beneath the confusion limit of Herschel, operating at a similar wavelength (see Figure 2).

Integrated, the number counts of the 450 μm–selected SMGs have allowed us to measure these galaxies' contribution to the cosmic infrared background (CIB) at 450 μm, the absolute intensity of which has been measured by COBE (Fixsen et al. 1998). With the current S2CLS data in the COSMOS/CANDELS field, we have directly resolved 16 ± 7% of the CIB (at 450 μm) into individual galaxies, an improvement over Herschel, which — owing to its higher confusion limit — has only directly resolved 5 – 6 % of the CIB at a similar wavelength (Oliver et al. 2010; Béthermin et al. 2012).

The 8" resolution and sensitivity of SCUBA-2 at 450 μm is a key advantage here; *(continued on page 9)*

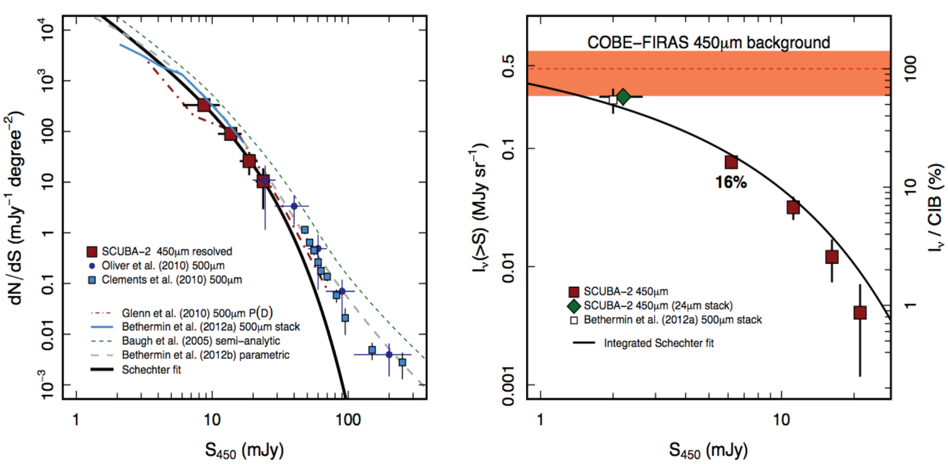


Figure 3: The first number counts of 450 μm-selected SMGs measured by the CLS. (Left) Differential number counts detected at 450 μm compared to those measured with Herschel (SPIRE) at 500 μm. (Right) The contribution of the detected 450 μm sources to the CIB measured by COBE/FIRAS at 450 μm. Figure taken from Geach et al. (2012).

NGLS: Science & Data Release

Christine Wilson (McMaster University, CA) on behalf of Frank Israel (Leiden Observatory, NL), Stephen Serjeant (Open University, UK) and the NGLS consortium

Survey Progress

With the allocation of 100 hours of SCUBA-2 observing time, the NGLS de-scoped the SCUBA-2 portion of its observing programme. We will use SCUBA-2 to observe all the spiral galaxies from the field and Virgo samples of the NGLS. In addition, we will observe most of the spiral galaxies from the SINGS part of the NGLS, leaving out a handful of (mostly early-type) spirals for which the CO observations and/or Herschel data suggest that the SCUBA-2 fluxes will be very weak. In total, we will observe roughly 100 spiral galaxies.

All of the galaxies will be observed using the DAISY mode to get the best noise per unit integration time. For a few of the largest galaxies, we may need to observe 2 – 4 overlapping DAISY fields to trace emission to larger radii. We will be able to assess how necessary this is from our existing observations of NGC 2403 and M51, two of the largest galaxies in our sample.

The NGLS is currently 25 – 30 % complete in its SCUBA-2 observations. In total, we have some SCUBA-2 data for 30 mostly spiral galaxies from the NGLS (at least one early-type galaxy was observed during Science Verification).

Some of the galaxies were observed with longer integration times during the Science Verification runs in December 2011 and January 2012, with the goal of understanding how the noise level in the maps decreases with integration time. Although we have not yet carried out this analysis, a side effect is that we have some quite deep images of galaxies, including an 850 μm map of the large nearby spiral NGC 2403 with a noise of 0.9 mJy/beam.

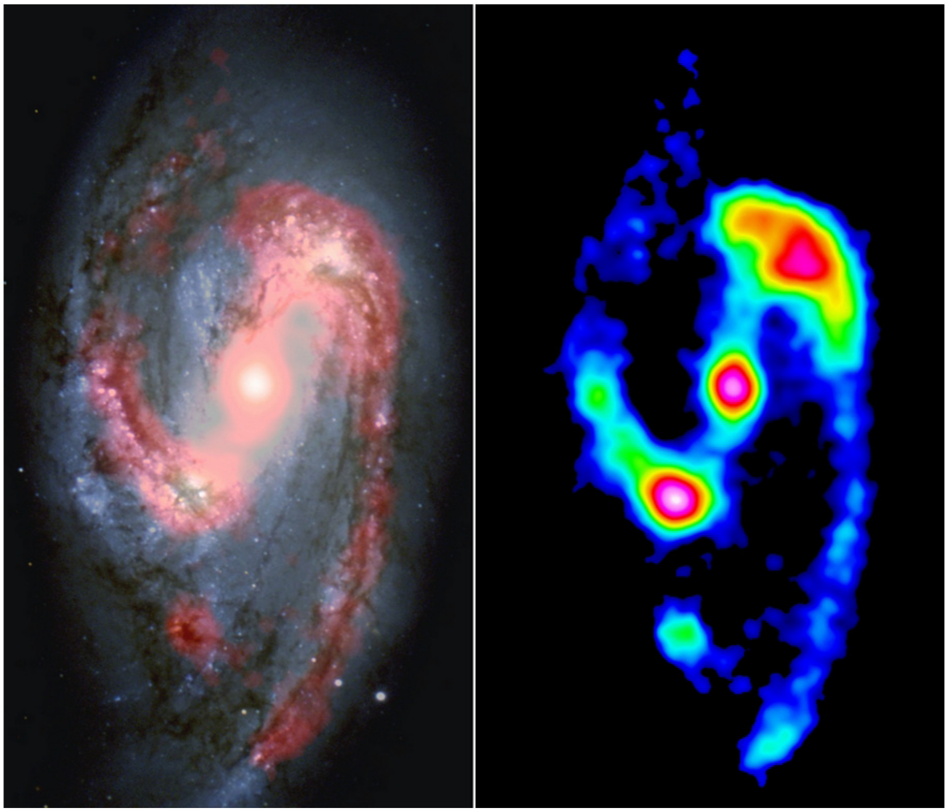


Figure 1: (Left) The red colours in this image show the galaxy M66 as it appears at the submillimetre wavelength of 850 μm, while the white background shows the galaxy as it appears in visible light. Regions of cold dust that appear as dark streaks in the white image glow brightly in the red image. (Right) The SCUBA-2 image at 850 μm seen on its own.

The next step will be comparing the SCUBA-2 data to images at other wavelengths to try to estimate how much faint extended emission is missing in the SCUBA-2 maps. For this last step, both the CO 3-2 images and the Herschel images, as well as global Planck fluxes at 850 μm, can be useful.

Publications & Projects

The overview paper presenting the overall survey structure as well as the CO data for the SINGS portion of the sample has now been published (Wilson et al. 2012). In addition to describing the survey structure and goals, this paper presents images from the CO data for all of the SINGS galaxies as well as an analysis of the correlation between the CO and far-infrared luminosity.

A second paper has been published describing ancillary H-alpha data that have been collected for the survey (Sanchez-Gallego et al. 2012). With this paper we now have available H-alpha images to trace the star formation rate for every galaxy in the NGLS.

We are planning for a first paper on one of the more photogenic galaxies from our sample. M66, or NGC 3627, (Figures 1 and 2) is a good candidate: it was observed during Science Verification, so has a better than average noise level; it has good 450 as well as 850 μm data; and a lot of data at other wavelengths (especially Herschel images) are available for comparison.

Other team members will be working

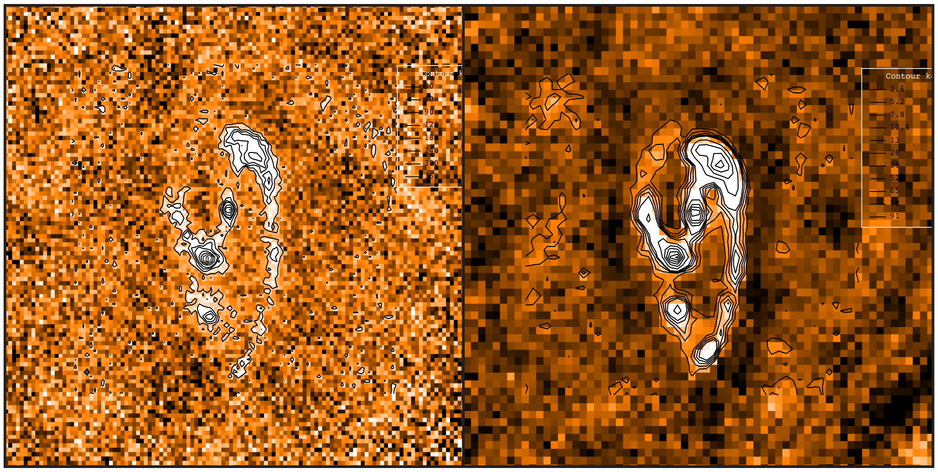


Figure 2: (Left) 450 µm map of M66 (also known as NGC 3627). Contours start at 2 σ (30mJy/beam) and the peak emission in the map is 360 mJy/beam. (Right) 850 µm map. Contours start at 2 σ (2.6 mJy/beam) and the peak emission in the map is 91 mJy/beam. The field of view is 7'.

on the gas-to-dust ratio and possibly combining the SCUBA-2 and CO data to evaluate the CO-to-H_2 conversion factor in some of the stronger NGLS galaxies. The data from the supplemental Virgo spiral survey has been reduced and analysed. They have been combined with the Virgo and field data from the NGLS and further divided the field sample into group and isolated galaxies to enable a better examination of the CO properties as a function of environment.

Plans are also underway to write a second paper examining the correlation of H-alpha with CO, HI, total gas, and other star formation tracers such as UV emission.

Release of HARP CO data

The raw data from the NGLS survey became public in the CADC archive in November 2010. The reduced CO data products were released to the community in November 2011. The data are available via a web site hosted at McMaster University: (http://www.physics.mcmaster.ca/~wilson/www_xfer/NGLS/), and the availability of this web site is advertised in the overview paper (Wilson et al. 2012). The images and data cubes are available in both NDF and FITS format, while the plots are available in both pdf and eps format. Work is underway to ingest the data products into the JCMT Science Archive.

Data Products

The data products that have been generated include: integrated intensity maps (moment 0) for each galaxy made with signal-to-noise masks set at 2.0, 2.5, and 3.0 σ; maps of the uncertainty in the integrated intensity for each galaxy made with signal-to-noise masks set at 2.0, 2.5, and 3.0 σ; velocity field maps (moment 1) for each galaxy with the same 3 signal-to-noise masks; velocity dispersion maps (moment 2) for each galaxy with the same 3 signal-to-noise masks; velocity cubes at the intrinsic ACSIS resolution as well as binned to 20 km/s resolution for easier inspection; plots of the integrated intensity maps with 2.0 and 3.0 σ mask cutoffs, both on their own and overlaid on digital sky survey maps, with contours linked to the rms noise level in the images.

Notes and scripts relevant to the reduction of the data have also been included in the public release.

Publications

The NGLS team has proved extremely prolific, with 8 publications to date resulting from NGLS data. These date back to 2009 and the ApJ paper by Wilson et al. on 'Star Forming Molecular Gas in Virgo Cluster Spiral Galaxies.' 2012 saw a further 2 papers in the NGLS series by Wilson et al. (2012) and Sanchez-Gallego et al., (2012). Further papers are in preparation.

Sanchez-Gallego, J. et al., 2012, MNRAS, 422, 3208
Wilson, C. et al., 2009, ApJ, 693, 1736
Wilson, C. et al., 2012, MNRAS, 424, 3050

S2CLS continued

(continued from page 7) it has allowed us to identify the counter-parts of the SMGs at optical and near-infrared (i.e. stellar light) wavelengths with near unambiguity. This is illustrated in Figure 3, where we compare a small area of our COSMOS/CANDELS map with the same region observed by Herschel at 500 µm, and at shorter wavelengths by Spitzer at 24 µm and HST in the optical/near-infrared. The origin of the bulk of the CIB light is obscured star formation (thermal emission of interstellar dust that has intercepted UV and optical photons emitted by young massive stars).

This radiation represents nearly 50 % of the total star formation activity in the Universe, and so resolving the CIB into the individual galaxies responsible for its emission is a critical step in identifying the galaxies forming the bulk of stars at this epoch. SCUBA-2 is blazing a trail in our continuing exploration of the submillimetre Universe, with S2CLS sure to be a treasure-trove from which many exciting discoveries and advances will be made.

Béthermin, M. et al., 2012, A&A, 542, 58
Coppin, K. et al., 2006, MNRAS, 372, 168
Fixsen, D. et al, 1998, ApJ, 508, 123
Geach, J. et al., 2012arXiv1211.6668G
Grogin, N. et al., 2011, ApJS, 197, 35
Oliver, S. et al., 2010, A&A, 518, L21

SLS: The Massive Core AFGL2591

Holly Thomas (JAC) on behalf of Matthijis van der Wiel (University of Lethbridge, CA) and the SLS consortium

The Spectral Legacy Survey

The Spectral Legacy Survey, or SLS, is the only exclusively heterodyne legacy survey at the JCMT. It was awarded 454 hours to achieve its goal of producing a complete chemical inventory of the star formation process.

To achieve this the survey chose to concentrate on four sources at different stages of stellar evolution. These are the Orion Bar, (a photo-dominated region), NGC 1333 IRAS4 (a low-mass star forming binary), AFGL2591 (a high-mass star forming core), and W49 (an active star forming region).

The SLS covers the spectral window of 330 – 373 GHz at a resolution of 0.8 km/s. The observations themselves are 2'x 2' jiggle maps centred on each source to provide spatial as well as spectral information.

AFGL2591 Emission Maps

AFGL2591 is an isolated massive core forming a star of ~16 M_{sun}. It lies at a distance of between 0.5-2.0 kpc (1.0 kpc is taken as the adopted value, see van der Tak et al. 1999) in the Cygnus-X region, and displays a massive bipolar outflow. It is a model candidate with which to investigate the molecular inventory of high-mass star-forming environments.

At a distance of 1 kpc the JCMT achieves a spatial resolution of 15,000 AU allowing it to probe the physical structure of the large-scale molecular envelope (10^4 – 10^5 AU) surrounding AFGL2591.

Altogether over 160 spectral features can be identified in the 300-373 GHz band, the majority of which are spatially unresolved. However 35 transitions have a spatial extent beyond the beam size and are spatially resolved. Figure 1 shows the integrated intensity images for these molecular transitions. For more details see van der Wiel et al. (2011).

All of the transitions show emission concentrated in the central region with the exception of the ^{12}CO, ^{13}CO and C^{17}O. The 'plume' extending to the north and seen in a number of transitions is also mirrored in the 850 μm background image. Interestingly, the warm (~200 K) transition, CH_3OH (12_1–12_0) shows a double peak indicating the possible presence of a secondary heating source. Although four emission sources (within 6") have been detected using interferometric observations (van der Tak et al. 1999, Benz et al. 2007); possible *warm* components indicated here, separated by >10", are entirely new.

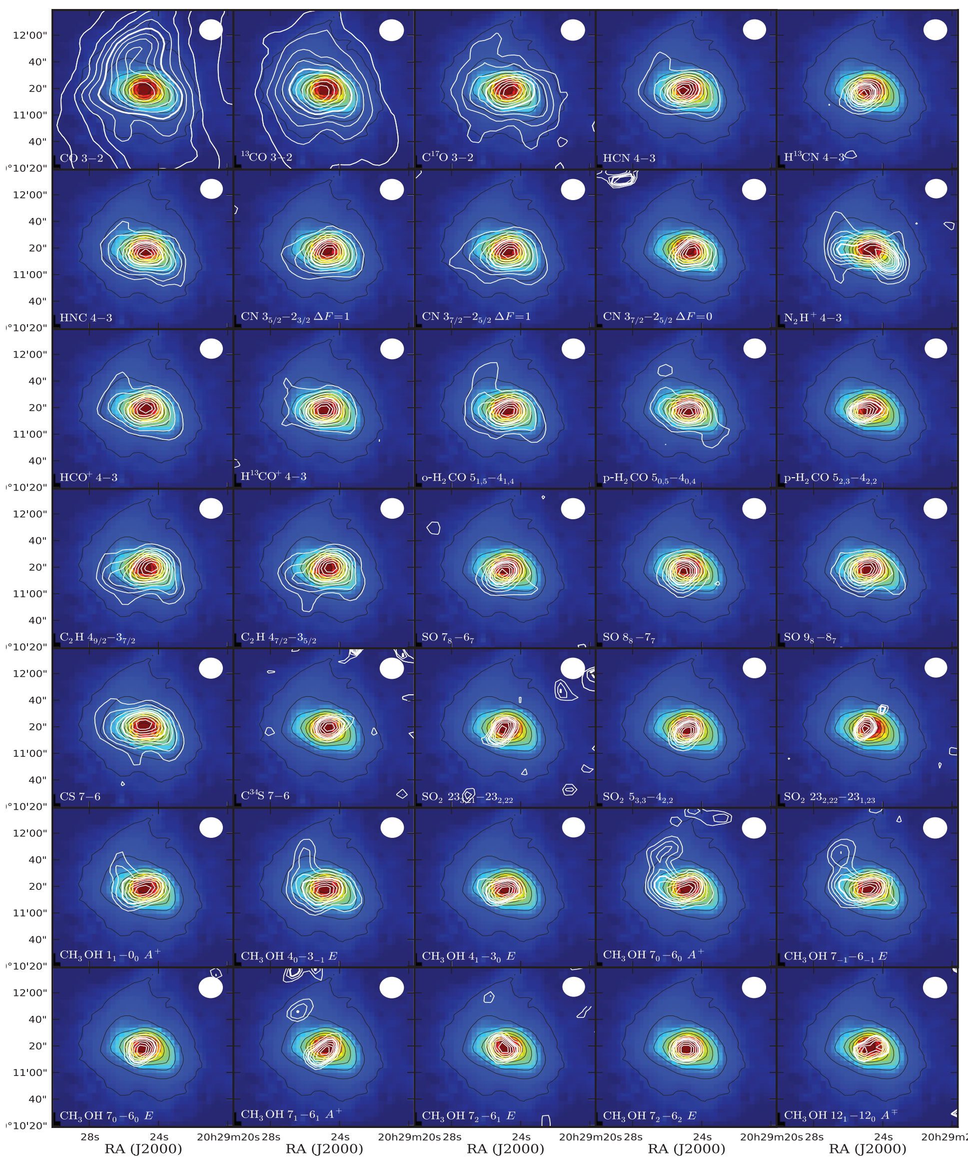


Figure 1: Integrated intensity plot for AFGL2591. The background colour image is the SCUBA 850 μm, while the white contours give the integrated intensity for the individual transitions (identified in the lower left corner of each panel). Figure taken from van der Wiel et al. (2011).

Modelling AFGL2591

Chemical modelling was performed with DUSTY (Ivezic et al. 1999) and RATRAN (Hogerheijde & van der Tak 2000). The density and temperature profiles of the dusty envelope were first modelled with DUSTY, using archived SCUBA 450 and 850 μm maps to determine the best fit model. The chemical transitions were then modelled using the ray tracing code RATRAN. With the envelope described by the DUSTY output, the chemical abundances could be modelled and the best match to the observational data identified.

The best-fit models suggest that the envelope is not an isotropic sphere. This can be accounted for either by outflow cavities or by clumpy structure on the scales of <10^4AU. The anisotropy indicated by the models is supported by the sub-structure seen in the integrated intensity maps of some of the transitions shown in Figure 1.

Figure 2 shows the suggested substructure for AFGL2591. This model is based on observations from this survey and from the literature.

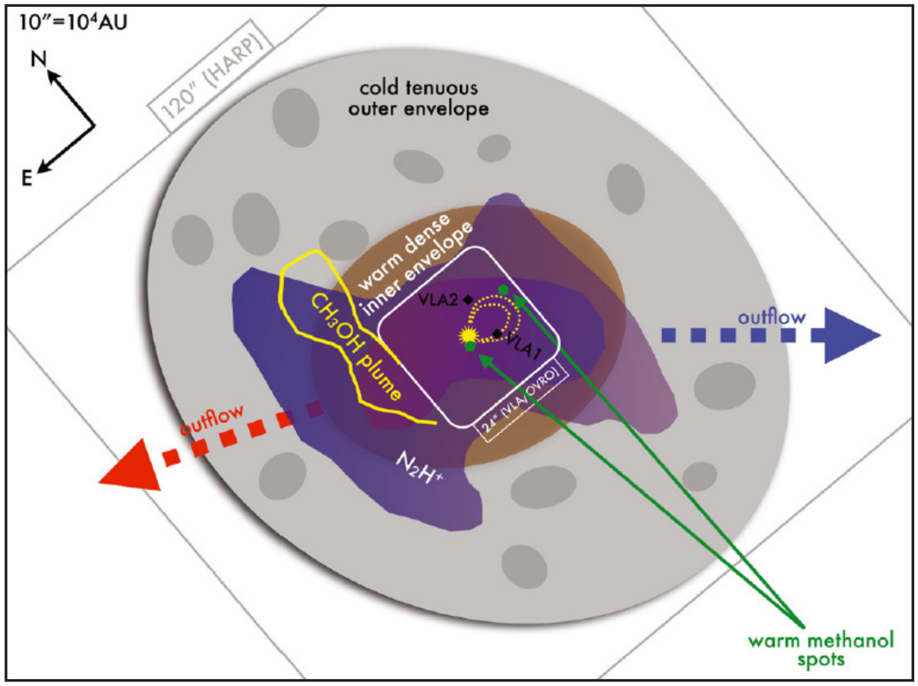


Figure 2: Overview of the observed sub-structure in the circumstellar environment of AFGL2591. The outer and inner envelopes, as well as the four-arm NH3 structure and the two warm CH_3OH spots are marked. The approaching (red) and receding (blue) arms of the outflow are indicated. The yellow star shows the position of the central heating source while the radio continuum sources (VLA1/VLA2) detected by Trinidad et al. (2003) are also given. Figure taken from van der Wiel et al. (2011).

SLS Data Analysis

The SLS has nearly reached completion, with just a few hours remaining. The data so far has yielded four publications. Data on W49 has been published by Roberts et al. (2011) and Nagy et al. (2012), while initial results from the Orion Bar and AFGL2591 have been presented in van der Wiel et al. (2009) and van der Wiel et al. (2011), respectively.

Investigation continues into the low-mass source NGC1333 IRAS4. This source requires a lower rms than the others so has been the last to reach completion. There is also further modelling work being carried out on the Orion Bar data. The available spectral data for this source has grown considerably since 2009.

Data Archiving

A further task for the legacy survey is the archiving of data. Like all JCMT data these will be stored at CADC. The SLS, as a line forest survey, faces special challenges regarding data reduction. The most prominent of these is spike removal, with spikes often indistinguishable from very narrow lines by data reduction software routines. Figure 3 shows an example of a typical region of a spectrum, the abundance of extremely narrow lines highlights the problem.

One of the major tasks over the next 18 months will be to develop the 'narrow lines' ORAC-DR recipe, allowing complete automation and ingestion of accurate reduced data into the JCMT Science Archive.

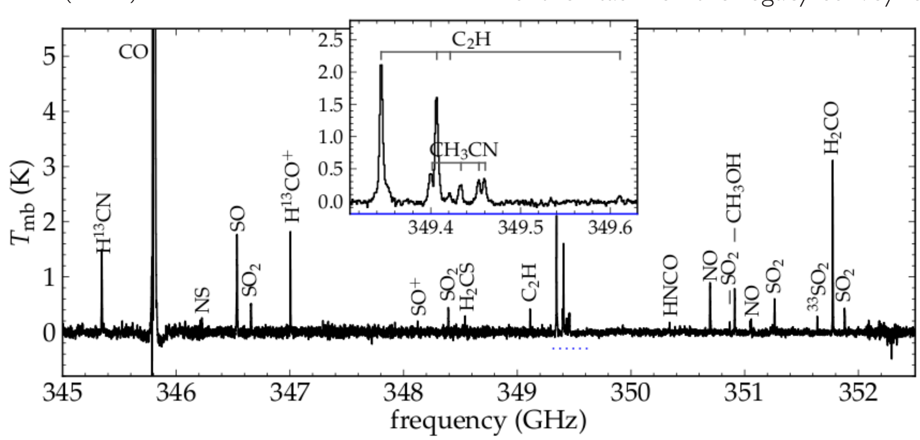


Figure 3: A 345 – 352.5 GHz sub-set of the full spectrum for AFGL2591. This illustrates the quality of the spectra and the rms achieved. The challenge of spike removal also becomes clear. This spectrum has already been de-spiked by hand. Credit: M. van der Wiel.

Benz, A. et al., 2007, A&A, 475, 549
Hogerheijde, M. & van der Tak, F., 2000, A&A, 362, 697
Nagy, Z. et al., 2012, A&A, 542, 6
Roberts, H. et al., 2011, A&A, 525,107
van der Tak, F. et al., 1999, ApJ, 522, 911
van der Wiel, M. et al., 2011, A&A, 532A, 88
van der Wiel, M. et al., 2009, A&A, 498, 161
Ivezi´c, Z., Nenkova, M. & Elitzur, M., 1999, ArXiv e-prints, 9910475

SASSy: Gets Underway

Mark Thompson (University of Hertfordshire, UK) and Andy Gibb (UBC, CA) on behalf of the SASSy consortium

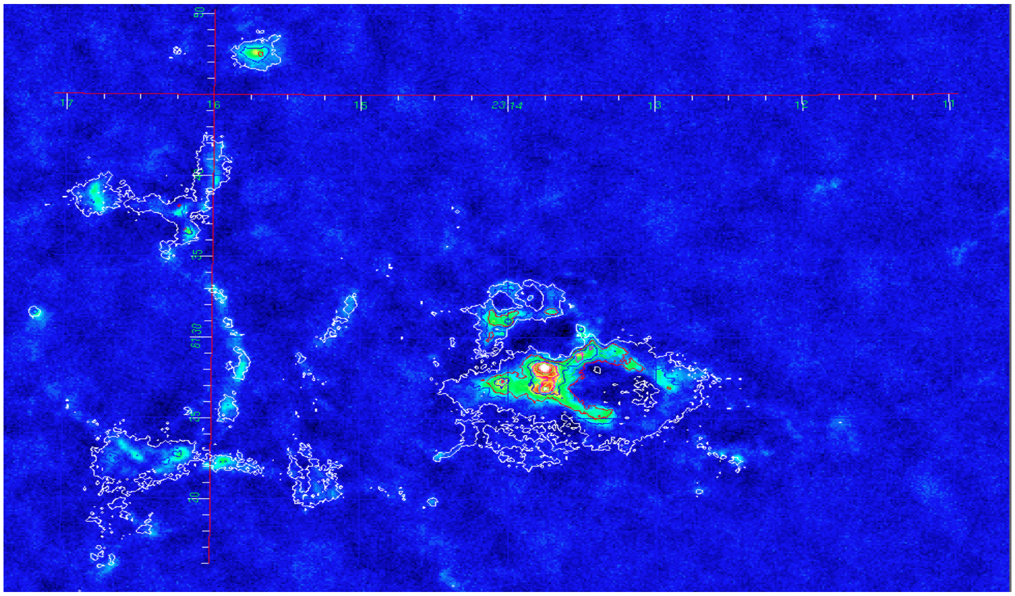


Figure 1: SASSy 850 µm map of the NGC 7538 complex acquired during SCUBA-2 Science Verification. The colour-scale shows the 850 µm continuum mapped with SCUBA-2, while the contours are of ^{13}CO J=3-2 integrated emission observed by HARP (Mottram, Thompson et al., in prep). The close correspondence of the ^{13}CO and SCUBA-2 emission shows that we can extract extended filamentary structure with SCUBA-2.

A Revised Survey

Following the survey redefinition process SASSy has been reborn as the SCUBA-2 Ambitious Sky Survey, with the aim of making the largest submillimetre map of the Outer Galaxy to identify the coldest and earliest regions of star formation. We began our survey operations in January 2012 by chasing a rapidly setting Outer Galaxy! We were only able to observe a few survey tiles before the Outer Galaxy set for the main part of the year, although progress has been picking up since August when the Outer Galaxy began to rise again.

Observations So Far

Most of our results so far have come from the data we acquired during the SCUBA-2 Science Verification phase on NGC 7538 (see Figure 1). We are currently fine-tuning our data reduction and source identification techniques on this data, while we process the bulk of data that has begun to arrive from August this year. The conclusion of our data reduction so far is that SCUBA-2 really does work well in poor weather [τ(225 GHz) > 0.12] and we are largely hitting our target noise in the fields we've observed so far. Two-degree wide PONG maps allow us to map large areas of sky efficiently. Our thanks go to all those at JAC and beyond who have worked so tirelessly to make SCUBA-2 a success!

Up to now we have managed to observe about 25 % of the survey area with much of this coming over the past couple of months with our first scheduled blocks of time in December and January. Another new development for SASSy is the approval of a PI programme in semester 12B to map a region between the ATLASGAL and SASSy surveys. This will enable a seamless map of the Galactic Plane at 850 µm from the Inner Galaxy to the Outer Galaxy as shown in Figure 2.

In conjunction with the Herschel Hi-GAL survey we will be able to construct SEDs for objects over the whole plane from 70 – 850 µm, tracking star formation along the entire length of the Perseus and Outer spiral arms.

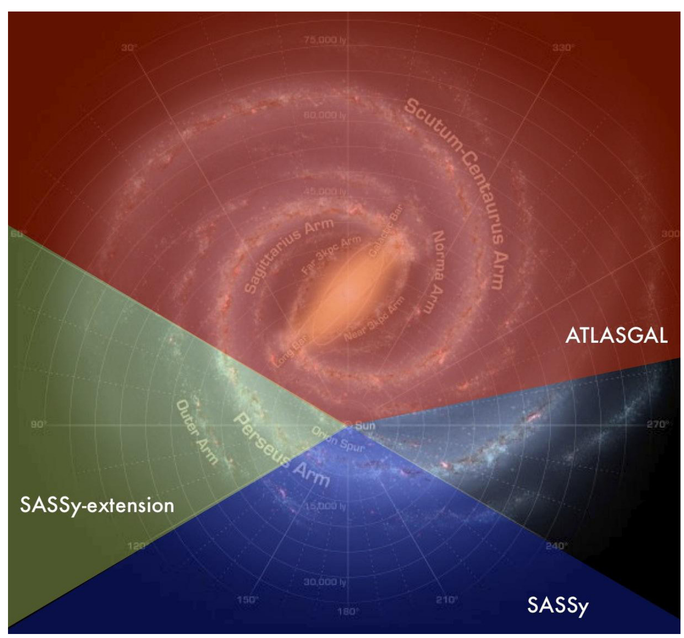


Figure 2: Artist's impression of the Milky Way showing the regions mapped by the ATLASGAL survey and those to be covered by the SASSy survey. SASSy is roughly twice as sensitive as the ATLASGAL survey. Credit: R. Hurt/M. Thompson.

JPS: Tackling Extended Emission

Harriet Parsons (JAC) on behalf of Toby Moore (LJM University, UK) and the JPS consortium

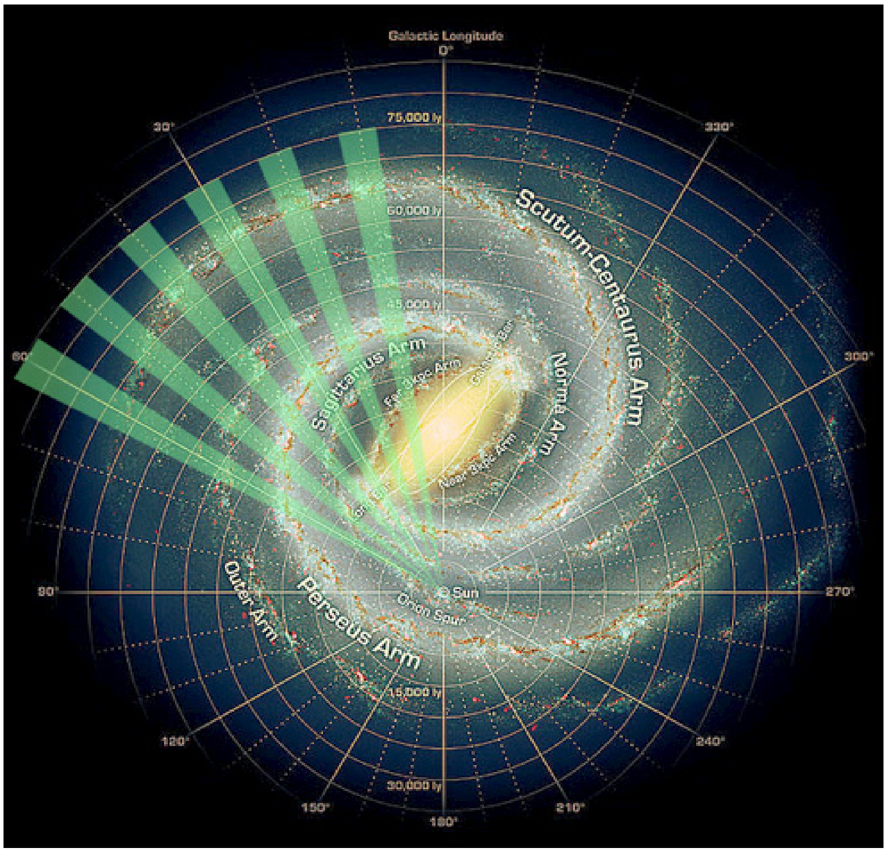


Figure 1: Galactic coverage of the JPS, covering the northern Galactic Plane.

Survey Overview

The JCMT Plane Survey (JPS), which will investigate star formation throughout the Galaxy using SCUBA-2, got underway in semester 12A. The aims for the JPS are to examine triggered and large-scale star formation in the galactic plane and to study the evolution of massive young stellar objects (YSOs), infrared dark clouds (IRDCs) and filaments, along with dust evolution and molecular cloud structure.

To achieve this, the JPS will observe six fields along the Galactic Plane at longitudes of 10, 20, 30, 40, 50 and 60 degrees (see Figure 1). Each field is just over 5 by 1.5 degrees in area. The coverage for each field is obtained by observing eleven one-degree PONG maps in a hexagonal pattern down to a target rms of 10 mJy with 8'' pixels, using multiple repeats on individual PONG maps. This strategy can be seen in Figure 2 which shows the tiles covered to date. This target rms level is over five times more sensitive than ATLASGAL and reaches a mass sensitivity of 100 M_{sun} at a distance of 20 kpc assuming a dust temperature of 20 K.

The JPS has been awarded 450 hours worth of band 3 time. This survey is well underway with approximately 70 % of the intended area observed, albeit not yet to the depth required. Survey completeness currently stands around 12 %.

Extended Emission

The greatest challenge for the JPS team is the extraction of large-scale structure from the data (see Figure 3). The Herschel Hi-GAL survey has revealed a wealth of large-scale filaments in the Galactic Plane and high fidelity SCUBA-2 images are needed to measure the SED and density profiles of these filaments.

Currently the best approach in recovering this emission has been to use publically available Herschel SPIRE 500 μm data as additional information in the reduction process. The SPIRE data is used as a mask to initially guide the map-maker to where emission is expected to be located. This SPIRE data in combination with the new 'skyloop' map-maker — currently under development — is yielding promising results.

The 'skyloop' map-maker is designed to take full advantage of all emission within a region. This method works by stepping through each iteration of the map-maker on all data. It then combines the data and continues on to produce the AST, NOI and FLT models. This information is then used on all data in the subsequent iteration. By utilising all the data available it is possible to boost the signal-to-noise within the maps aiding in the extraction of this large-scale emission.

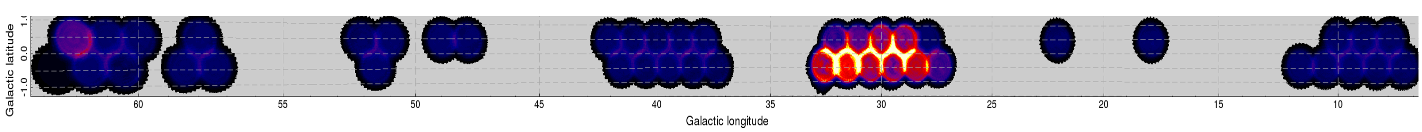


Figure 2: The survey area covered so far, with brightness indicating total exposure time. The tiling pattern used is easily seen, particularly for the bright l=30° region.

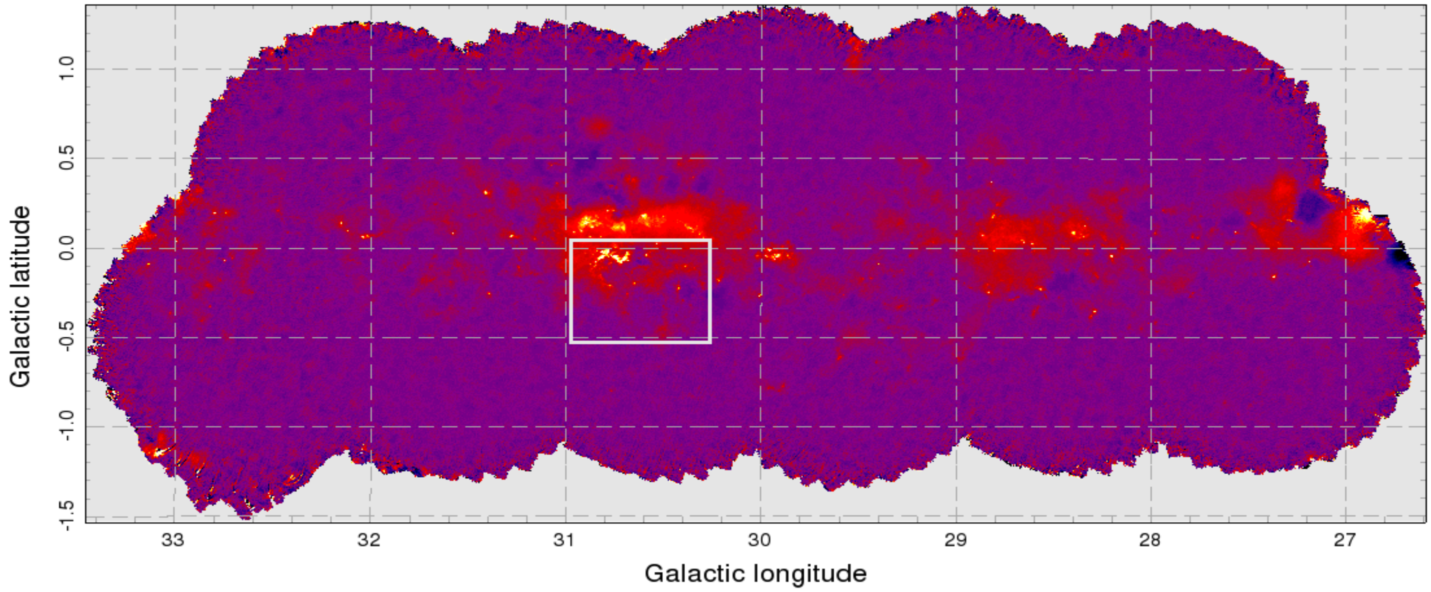


Figure 3: SCUBA-2 850 μm image of the Galactic Plane around l=30°. The image was reduced using the 'skyloop' map-maker currently under development.

Although still in development, this technique is producing promising results (the white box in Figure 3 marks the W43 region shown in Figure 4).

For a complete description of the 'skyloop' map-maker, (formerly known as the 'inside-out' map-maker), see the JCMT Pipelines and Archives blog (http://pipelinesandarchives.blogspot.com/2012/10/inside-out-map-making.html).

A second approach which the JPS team is taking to understand the recovery of large-scale structure is to utilise the Herschel data as a test data set. In this work Herschel data is fed into the current reduction method as raw data. The output can be compared to the SCUBA-2 reduction and used as an indicator of the success of our recovery of extended emission.

What's Next?

Looking to the future the JPS is anticipating a productive 13A semester with the survey currently holding the highest scheduling priority of all the legacy surveys due its low completion rate. The increase in expected data will make 2013 an exciting year for the survey team. Priorities for the team will be to smooth out and finalise the data reduction process, work on source extraction and publish the science!

On global scales the data collected by the JPS will be used to unlock the star forming secrets of the Galaxy. The large coverage will allow comparisons between modes of star formation to be made, investigating the dominating modes of star formation (i.e. global shear, OB/HII/ triggering) over varying size scales. The volume of data collected, combined with complementary data from other surveys such as CORNISH, Herschel, UKIDSS etc., will also enable statistical lifetimes to be calculated.

With the l = 30° field almost completed to the target rms it is expected that these observations, containing both G29.9 and W43 — two massive star forming regions, will likely form one of our initial publications.

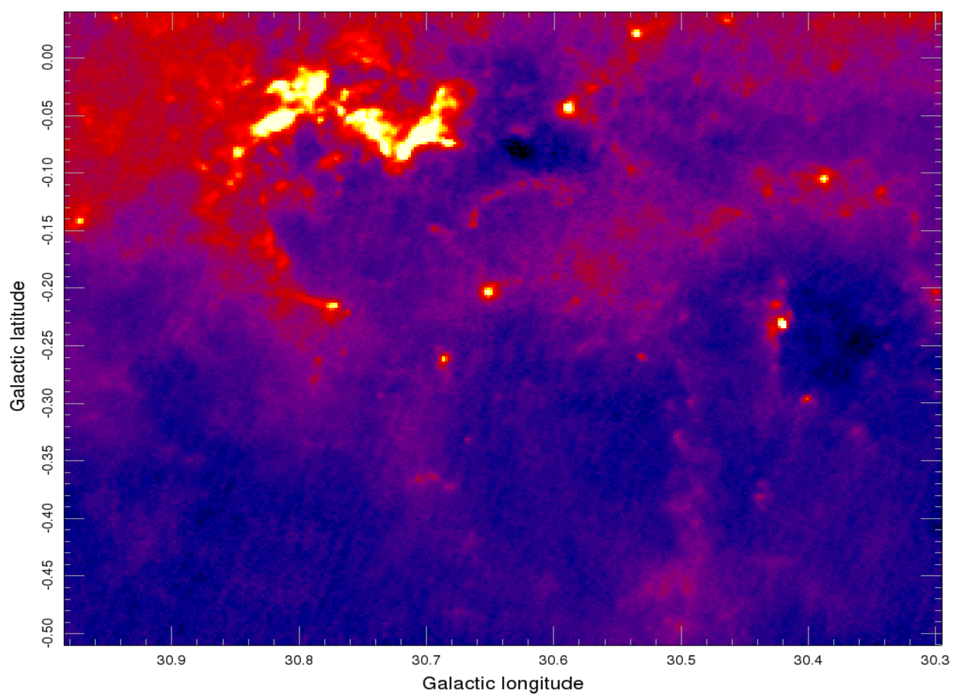


Figure 4: An 850 μm zoom into the region close to W43 (the bright Z-shaped structure). This region is marked by the white box in Figure 3.

GBS: Survey Update

Jenny Hatchell (University of Exeter, UK) on behalf of the GBS consortium

Survey Summary

The JCMT Gould Belt Survey of nearby star-forming regions got off to a good start in 2012. With the weather cooperating, nearly a third of the SCUBA-2 survey is complete at the time of writing, including partial coverage of well-known molecular clouds in Perseus, Orion, Taurus, Ophiuchus and Serpens/Aquila.

A select team of data reduction experts is valiantly working through the volumes of data using purpose-bought high-memory computers. At this point, the dust continuum maps are gradually becoming available to the 50+ survey members for analysis. In parallel, analysis of the molecular line data from HARP continues, yielding complementary velocity and temperature information for selected sub-regions of the clouds.

The GBS aims to address several of the major unsolved questions in star formation: the evolution of pre/protostellar cores, the origin of the initial mass function, and the link between star formation and molecular cloud properties, including the relative importance of magnetic fields and turbulence.

The targets are nearby clouds within 500 pc where the angular resolution is high enough to separate individual pre/protostellar cores (0.1 pc). SCUBA-2 datasets are highly complementary to Herschel as they cover long wavelengths (450 and 850 μm) and with higher angular resolution.

Science Results

Reduced SCUBA-2 data are yielding the first science results: the dust opacity spectral index in Perseus B1 (Sadavoy et al. submitted) and in Orion (Coudé et al. in prep.), identifying the coldest cores in Taurus, investigating filament structure (Salji et al. in prep.), and measurements of the temperature structure of the NGC1333 cluster in Perseus (Hatchell et al. 2013, discussed further below). Additionally, the contribution of CO line contamination to the SCUBA-2 bands has been characterised (Drabek et al. 2012), which should be of value to SCUBA-2 observers of regions near and far.

The applications of SCUBA-2 data for nearby star-formation studies are illustrated by the work on temperature structure in NGC1333 (Hatchell et al. 2013). With high-quality 450 and 850 μm data, it is possible to make reliable spectral index maps which are sensitive to temperature and/or dust opacity variation.

We used data on NGC1333 from the February/March 2010 SCUBA-2 shared risk campaign, when SCUBA-2 only had one of four arrays installed at each wavelength, as a pilot project for the full GBS data. We produced 450/850 μm ratio maps, which showed a significant ratio rise towards the NGC1333 reflection nebula. We interpreted this as dust heating by the cluster B stars (SVS3), and fitted with

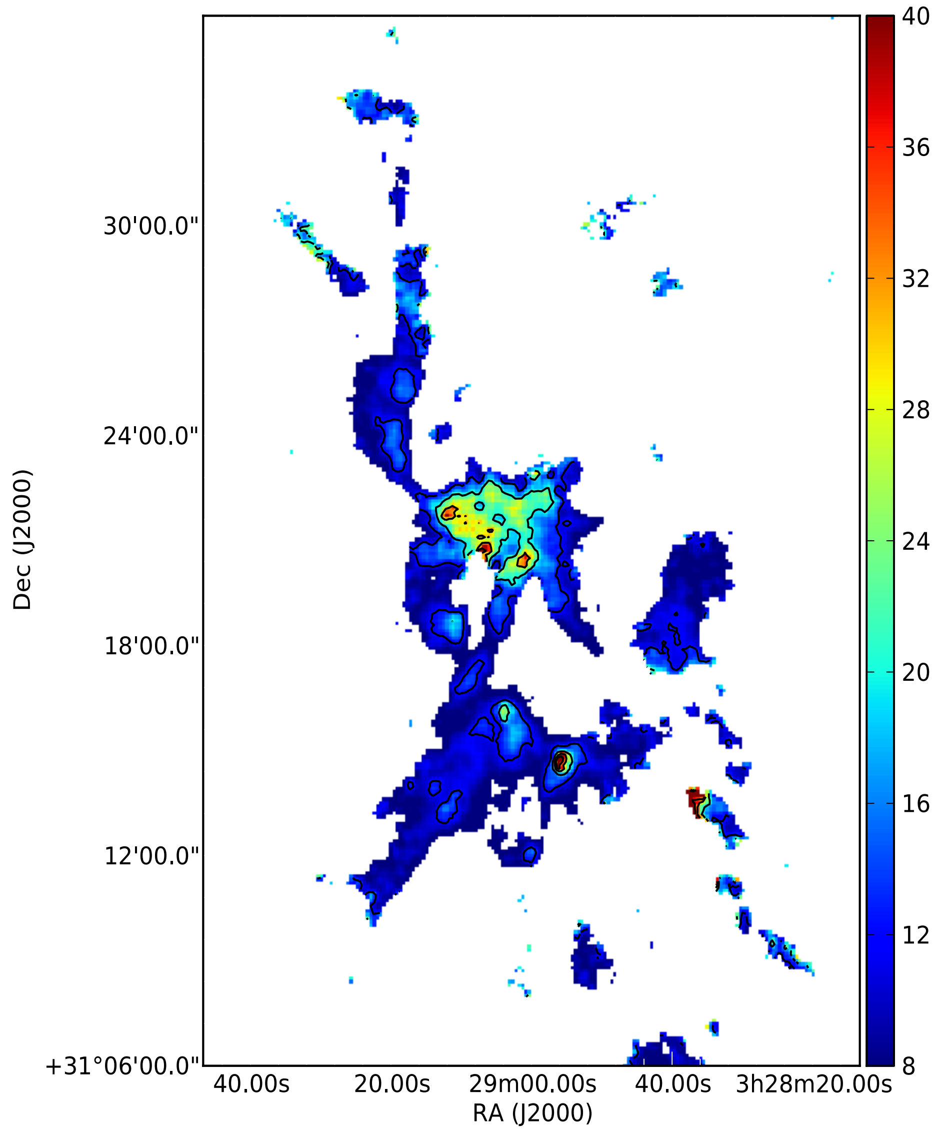


Figure 1: NGC1333 dust temperature map at β =1.8 in units of Kelvin. Contours are at T_{dust} = 12, 20 and 30K. Figure taken from Hatchell et al. (2013).

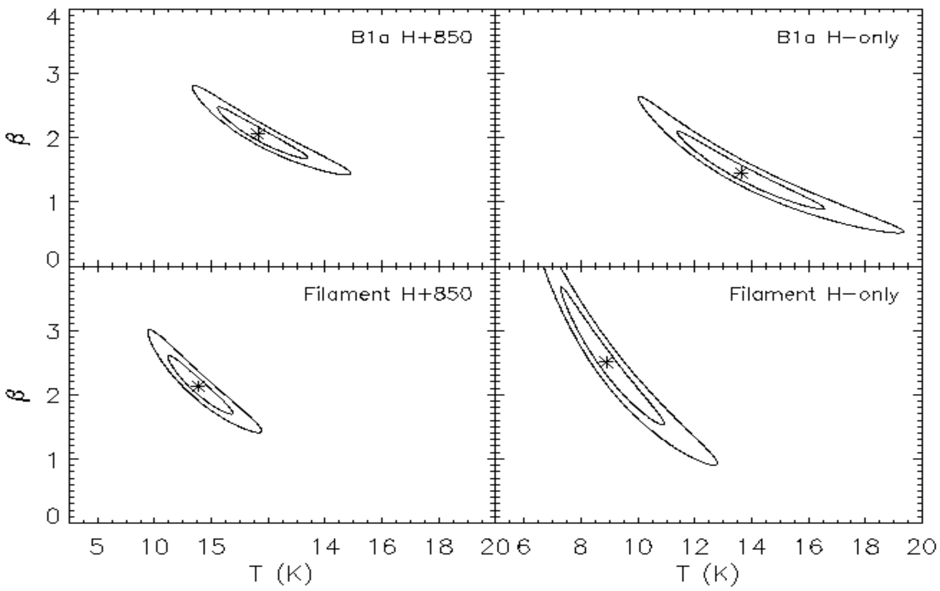


Figure 2: β - temperature plots for 4 GBS sources. The plots are well contrained by improved deteminations of β.

a constant dust opacity (β=1.8) to make a temperature map (see Figure 1). Widespread dust temperature rises to 20 – 40 K are found in the northern part of NGC1333 and towards several other luminous protostars.

The temperature rises suggest the possibility that the existing B-star SVS3 is influencing the next generation of stars through radiative feedback, raising the thermal Jeans length and potentially inhibiting sub-fragmentation leading to more massive star formation. We await the processing of the full SCUBA-2 NGC1333 data to reassess the masses of the cores in the NGC1333-N region and determine if they contain enough material to form further B stars.

Using Compatible Datasets

The combination of the SCUBA-2 dust temperature and HARP ^{12}CO excitation temperature maps at similar resolution is useful in determining the location of heating sources. ^{12}CO is very optically thick and traces only the front side of the cloud, whereas SCUBA-2 maps emission-averaged dust temperature from the entire optically-thin column. Hence high CO excitation temperatures indicate heating sources close to the front of the cloud, whereas high dust temperatures point to embedded sources. With the resolution of JCMT, this kind of analysis is possible for individual protostars.

The next step, combining SCUBA-2 data with Herschel data, is worked on with a focus on determining the dust opacity spectral index beta (Sadavoy et al., submitted). The dust opacity is important when converting far-infrared/submillimetre emission to mass, therefore, we need to constrain β to improve our ability to measure dust masses. Unfortunately, measurements of β are closely linked with the dust temperature. For example, β variations can be estimated from SCUBA-2 data alone using the 450/850 μm spectral index, but these measurements assume the dust temperature is constant (Coudé et al. in prep).

Conversely, Herschel data allow the dust temperature to be determined very well with measurements covering the peak of the spectral energy distribution for cold (10 – 30 K) clouds. The Herschel data however, are unable to measure β well. Therefore, combining Herschel with the long-wavelength data from SCUBA-2 in a joint fit of temperature and β provides better constraints on the dust opacity and hence on pre/protostellar masses.

Figure 2 highlights our improved determinations of β and temperature. We find improvements in our ability to determine β by a factor of 2 and improvements in our ability to measure temperature by 40 %. For the B1 star-forming region, we find variations in β of order 25 % between the protostellar cores and ambient material.

GBS Spectral Line Data

The GBS has mapped sub-regions of Taurus, Serpens, Orion A, Orion B, Serpens, Taurus, and Ophiuchus with HARP in $^{12}CO/^{13}CO/C^{18}O$, primarily in order to study the kinematics of the gas (Davis et al. 2010; Graves et al. 2010; Buckle et al. 2010; Buckle et al. 2012).

The CO isotopologues probe the physical characteristics of the cloud, including linewidths, excitation temperatures, ^{12}CO and ^{13}CO optical depths and systematic velocity gradients. From these measurements, the mass and energetics of the clouds can be determined, including the total mass, momentum, and energy in the outflows for comparison with the cloud mass and energetics.

An interesting question is whether feedback from protostellar outflows has a significant effect on subsequent generations of stars, and we are finding that outflows input a varying amount of kinetic energy, depending on region, in some regions comparable to the total turbulent energy in the region.

The results have also been used for a statistical cross-cloud study of depletion (Christie et al. 2012) which shows significant variation in CO depletion between clouds, with Taurus the most heavily depleted and Ophiuchus the least, and demonstrates that protostellar envelopes are generally less depleted than starless cores.

Buckle, J. et al., 2012, MNRAS, 422, 521
Buckle, J. et al., 2010, MNRAS, 401, 204
Christie, H. et al., 2012, MNRAS, 422, 968
Davis, C. et al., 2010, MNRAS, 405, 759
Drabek, E. et al., 2012, MNRAS, 426, 23
Graves S. et al., 2010, MNRAS, 409, 1412
Hatchell, J. et al., 2013, MNRAS, 429, 10
Sadavoy et al., ApJ, submitted

SONS: Spectacular Results

Brenda Matthews (NRC, CA), Wayne Holland (ROE, UK), Jane Greaves (University of St. Andrews, UK) and Jonathan Marshall (UAM, ES) on behalf of the SONS consortium

SONS Science Goals

The SONS survey targets 115 nearby stars searching for debris signatures in the form of dust emission at 850 µm. All stars in the sample are known to be disk hosts based on observations at (usually) shorter wavelengths.

The aim of SONS is to characterise these disks to the fullest extent possible by: (1) providing direct dust masses that cannot be obtained from shorter wavelengths; (2) adding to the far-IR/submillimetre spectrum to constrain the dust size distribution; (3) using the power of a 15 m telescope to resolve disk structures around the nearest systems; and (4) looking for evidence of resonant clumps and other features in resolved structures that could be indicative of unseen perturbers, such as planets. A major strength of SONS is that imaging of individual objects produces publishable results ahead of the statistical survey conclusions.

The Evolution of the Survey

Survey enthusiasts will note that the SONS programme is significantly changed from its original SUNS form (SCUBA-2 Unbiased Nearby Stars, which targeted 500 stars). This change was necessary because of the significant impact of Herschel's debris disk key programmes which have identified the candidate disks in the nearby volume of stars targeted by SUNS. The rescoped SONS survey acknowledges these advances and focusses on known disks within 100 pc, searching for 850 µm submillimetre emission associated with disk systems deemed to have the highest probability of detection. The original SUNS allocation of 330 hours was reduced to 270 hours for SONS, but the amount of time allocated in Grade 2 weather increased by more than a factor of 2 to 135 hours.

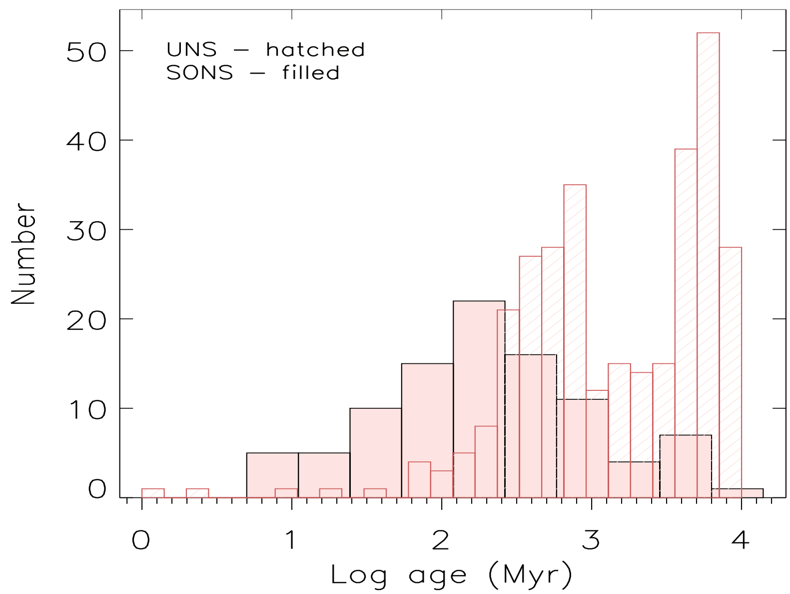


Figure 1: This histogram illustrates the difference in ages for the rescoped SONS survey versus the original SUNS AFGK star survey sample. A wider range of disk ages is covered by the SONS survey.

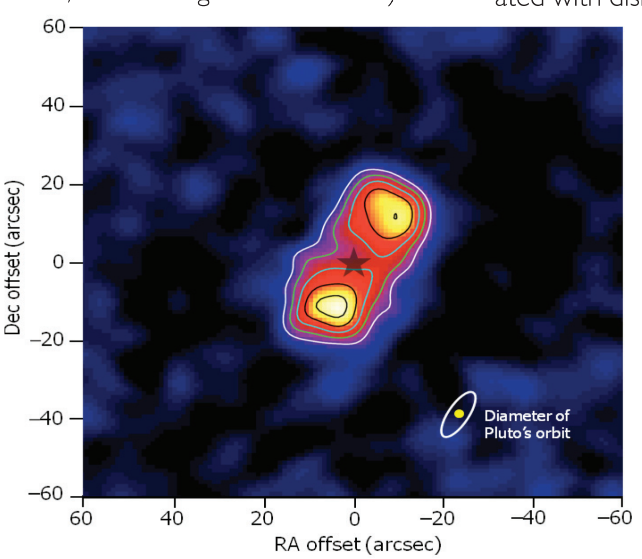


Figure 2: 850 µm map of the Fomalhaut debris disk. Contours start at 3 σ and increase in steps of 2 σ. The star gives the position of Fomalhaut itself.

The increased volume of SONS (45 pc to 100 pc) increases the number of disk-host targets of younger ages (see Figure 1), increasing the likelihood of detections and enhancing the survey's potential to track evolutionary trends in cold disk components, while minimising inclusion of protoplanetary disks from nearby associations that would dilute the debris disk sample.

Observational Progress

The survey began in February 2012. As of mid-January 2013, the SONS survey is 50 % complete against the total allocation of 270 hours. We have observed 60 of the 115 targets to a 1σ sensitivity level of 2 mJy or less at 850 µm. Our Science Verification data confirmed that faint, unresolved disks of order 5 – 10 mJy can be detected at flux levels commensurate with previous studies and that SCUBA-2 is capable of accurately reproducing the morphology of extended disk structures, such as the inclined disk of Fomalhaut, shown in Figure 2.

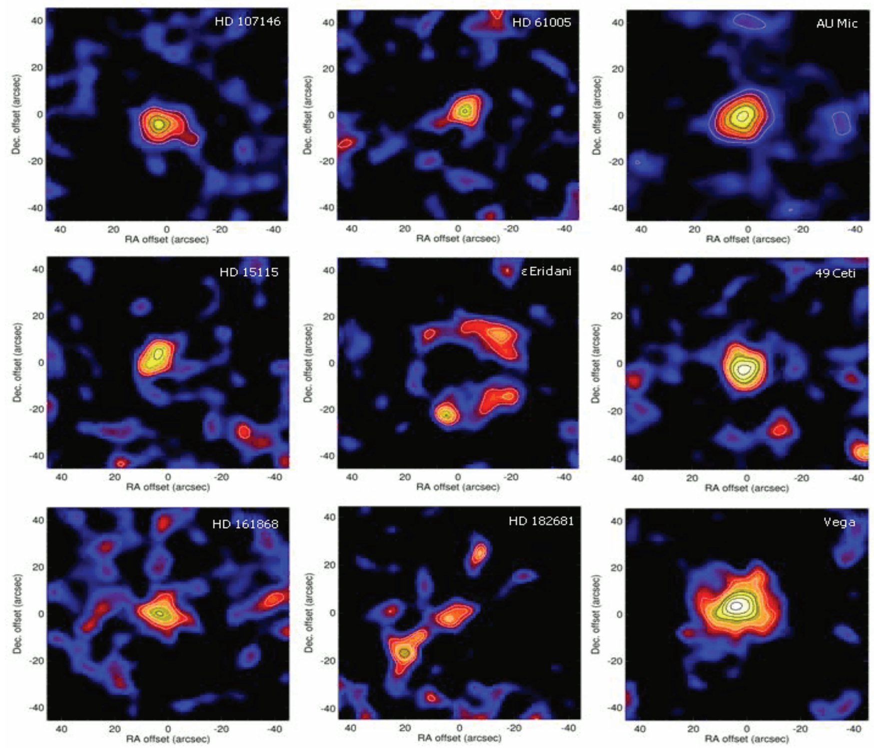


Figure 3: A selection of SCUBA-2 observations of debris disks from the SONS survey. The contours on each image start at a level of 3 σ and increase in 1 σ steps (except for AU Mic, which has 2σ steps).

To date, SONS has more than doubled the number of detected disk images at 850 µm. SCUBA-2's predecessor, SCUBA, was the first instrument at any wavelength to successfully resolve a large number of debris disks. At the time of its demise, more than half the total number (just over a dozen) of resolved images of all debris disks were from SCUBA. Thanks to Herschel, that number is now well above 70. The highest scientific dividend comes when disks are resolved at multiple wavelengths, since this places the strongest constraints on models of the dust distribution and evolution in the system (Wyatt 2006). Thus SCUBA-2 remains extremely important and SONS is well placed for success.

Science Results

In Figure 3, we show a sampling of our detected disks, including well-known disks previously resolved by SCUBA (i.e. Epsilon Eridani and Vega). In addition, disks which were detected by SCUBA have now been imaged, such as AU Mic and 49 Ceti. Several of the detected disks (i.e., HD182681, HD161868, HD 15115) have not previously been detected in the submillimetre, so these enhance our understanding of the distributions and character of the coldest dust in debris disk systems. Of the 67 stars observed so far by SONS, 27 (40 %) have shown definite signs of dust emission at 850 µm.

A Case Study of 49 Ceti

The 49 Ceti debris disk is remarkable as, unlike most others, it contains molecular gas. The CO detected is thought to arise from ices sublimating after comet collisions, as it is unlikely to be a remnant of the protoplanetary disk at 49 Ceti's age of 40 Myr (Zuckerman & Song 2012).

We imaged the disk with SCUBA-2, and resolved its dust extent for the first time at 450 µm. Figure 4 shows that the disk is oriented at about 120 degrees east of north, plus there is a compact (probably background) object to the north. The disk was also well detected at 850 µm (dashed contours). The scale bar shows that rocky debris extends out to radii of about 300 AU, which is the same as inferred from a JCMT/RxB CO spectrum (Dent et al. 2005). This implies that the dust and gas are co-spatial, and so supports the cometary break-up origin. A side-effect appears to be that the dust spectral index becomes similar to that of gas-rich protoplanetary disks, so gas drag is probably influencing particle collisions and hence the size distribution and flux-ratio. These phenomena could be a valuable signpost to systems with a lot of dynamical activity, possibly stirred by planets, or by dwarf planets within the comet belts.

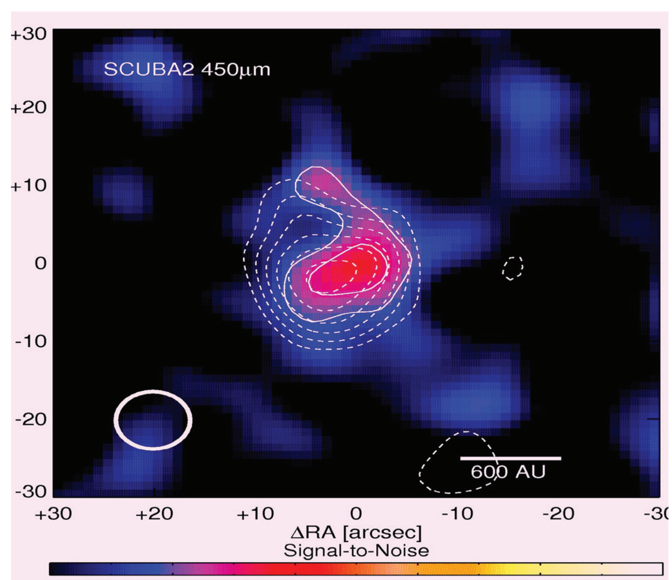


Figure 4: Map of the molecular gas hosting debris disk 49 Ceti. Colour-scale shows the 450 µm emission and dashed contours show the 850 µm data.

A Summary of SONS Status

The quality of the SONS data from SCUBA-2 has been excellent and the detection rate for disks is close to 40 %, already more than doubling the number of imaged debris disks at 850 µm, (this will likely increase when the survey reaches its full depth). A number of high-profile papers are in preparation — watch this space!

Dent, W., Greaves, J. & Couslon, I., 2005, MNRAS, 359, 663
Wyatt, M., 2006, ApJ, 639, 1153
Zuckermnan, B., & Song, I., 2012, ApJ, 758, 77

Venus Transit: "Once in a Lifetime"

Brad Sandor (Space Science Institute, US)

On June 5, 2012, Venus passed between the Earth and Sun. This rare event will not happen again until the 22nd century. While thousands of people across the world were watching this event, the JCMT was staring with a special interest.

Venus Science with the JCMT

Since 2000 we have used the JCMT to measure winds in the Venus nightside lower thermosphere (110 km altitude), based upon observation of Doppler shifted ^{12}CO absorption lines. Velocity at the disk centre is defined to be zero, based on knowledge that vertical winds are negligible relative to horizontal ones. Placement of the 14" B-band beam on the 60" Venus disk at inferior conjunction allows for mapping of the nightside. Comparison of disk centre and non-centre absorptions across many spectral channels allows measurement precision (typically $\pm$10 m/s) limited by signal-to-noise, rather than by spectral resolution.

Foreground CO in the cold (140 K) thermosphere presents absorption lines against continuum emission from the warm (260 K) lower atmosphere, which becomes optically thick at 50 km altitude. The atmospheric limb, presented against the background of cold space, contributes negligible emission, such that limb-placed beams see only absorption.

JCMT observations since 2000 reveal nightside winds are extremely time variable. Model fits to spatially mapped winds show the lower thermosphere to be a transition region between the zonal retrograde West to East circulation of the lower atmosphere (as seen in cloud top images), and the subsolar to antisolar (SSAS) axisymmetric flow of the upper atmosphere. Observed wind patterns at 110 km are well matched with model circulation that includes both components. Relative strength of the zonal and SSAS flows is time variable, with the zonal pattern dominant in 90 % of observations.

Other investigators measuring winds at 110 km on the dayside also find zonal and SSAS contributions to the wind field, but on the dayside it is the SSAS component that is dominant, and zonal flow is always weak. Clearly a transition between day and nightside circulations must exist at or very near the Venus terminator, but no one had ever measured cross-terminator winds. Under ordinary circumstances this is not possible with the JCMT, because area of the terminator inside the JCMT beam projection on Venus is tiny.

Science During Transit

During the transit, the cold 140 K Venus atmospheric limb is presented in front of the 6000 K solar photosphere, a temperature contrast so great that limb-pointed observations with the JCMT are dominated by absorption through the limb, with negligible contribution from the nightside disk. During transit, the Venus atmospheric limb is by definition also the Venus terminator. On June 5, we observed submillimetre line absorption spectra of ^{12}CO (346 and 230 GHz) around the Venus limb, obtaining first-time cross terminator wind measurements based upon Doppler shifts of the observed lines. Terminator winds were predominantly SSAS (rather than zonal), hence presenting a pattern like the dayside (rather than

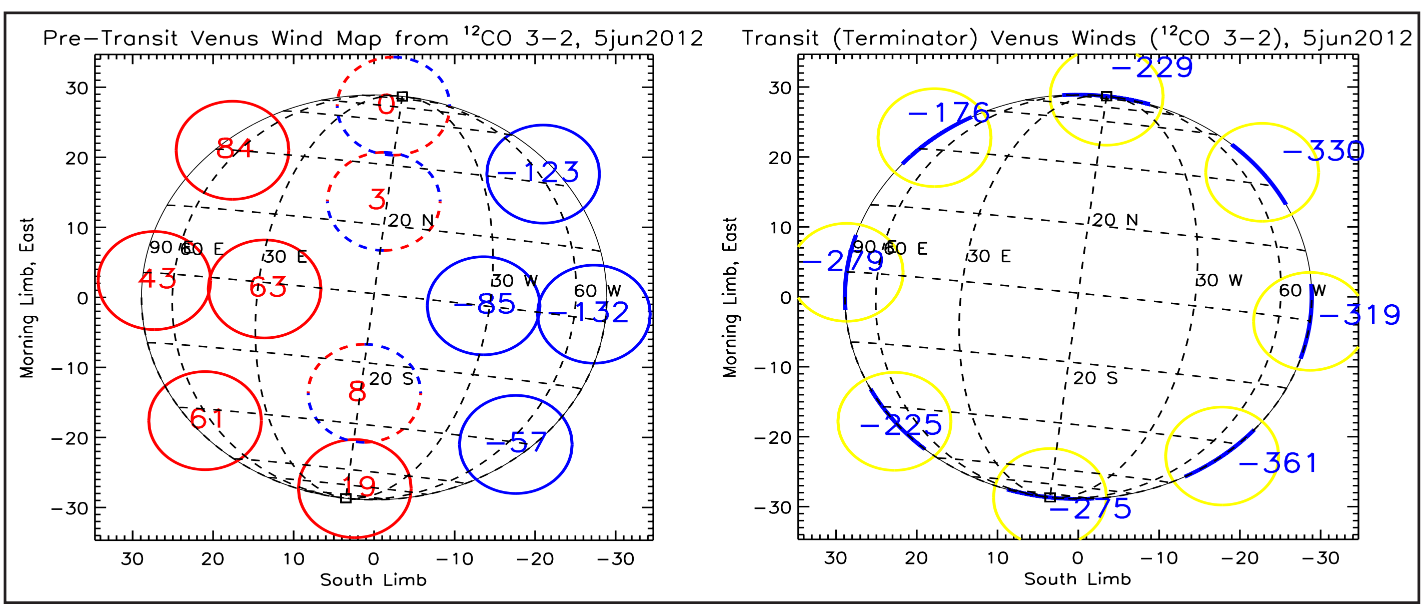


Figure 1: (Left) Pre-transit and (Right) during transit wind maps of the disk of Venus. The circles show the JCMT beam overlaid on the disk, while the numbers give the beam-averaged wind speed.

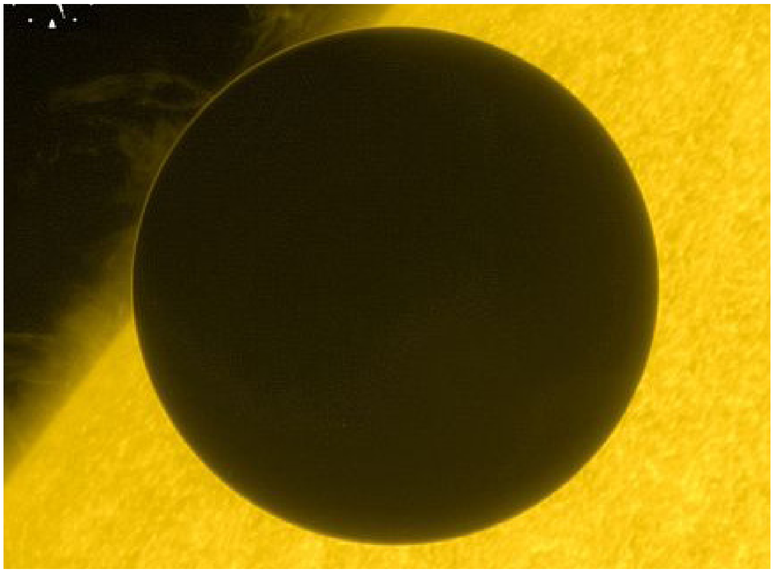


Figure 2: Venus crossing the face of the Sun during transit captured with Hinode. Credit JAXA/NASA.

nightside). Surprisingly, cross terminator flow speeds are in most cases supersonic, in some cases exhibiting Mach numbers exceeding 1.5 relative to the 200 m/s sound speed. Supersonic flow had never previously been seen or anticipated, and presents an unprecedented puzzle in understanding atmospheric dynamics.

Two of the wind maps observed with the JCMT on June 5 are shown in Figure 1. Prior to the beginning of transit, nightside winds (left-hand panel, Figure 1) were measured in the conventional manner. Red/blue circles correspond to the 14" beam footprint placed on the 60" Venus disk. Retrieved wind speeds correspond to the spatial average within each beam. Red indicates receding winds (red-shift), and blue indicates approaching winds (blue-shift). The three beams with dashed red/blue borders represent zero wind (within the ± 10 m/s uncertainty).

The circulation pattern is predominantly zonal retrograde, West to East flow, typical of the nightside. A wind map observed 6 hours later, during transit, is also shown (right-hand panel, Figure 1). In this case the measured winds are from arcs along the terminator (shown in blue). Terminator winds follow the SSAS pattern, and exceed Mach 1 (200 m/s) at 7 of the 8 observed limb positions.

Figure 2 shows an optical image of Venus during transit, throwing the terminators into sharp relief against the solar photosphere.

The SCUBA-2 Lensing Survey

James Simpson (Durham University, UK) and the S2LS consortium

During semesters 12A/12B we have undertaken a survey of 42 massive galaxy clusters at 450 and 850 μm with SCUBA-2. Our goal is to detect submillimetre galaxies (SMGs) which have been gravitationally lensed by the foreground clusters (see Figure 1).

The benefit of this survey is that the lensing process magnifies these galaxies, increasing their flux in the submillimetre waveband and at all other wavelengths, as well as increasing the effective resolution of our observations. As a result it is possible to detect, and study in detail, SMGs which would otherwise be fainter than the JCMT's confusion limit. We expect to detect ~200 lensed SMGs (>4) down to an intrinsic flux of <1mJy, constraining the form of the faint number counts along 42 independent sightlines (similar depth early ALMA studies are likely to suffer from cosmic variance uncertainties).

For individual sources we will then combine our 450- and 850-μm data with Herschel observations of all 42 clusters to constrain the spectral energy distributions from 100 – 1000 μm, allowing us to derive properties such as the far-infrared luminosity and dust temperature, which we can use to compare these systems to the more luminous sources seen in blank-field surveys.

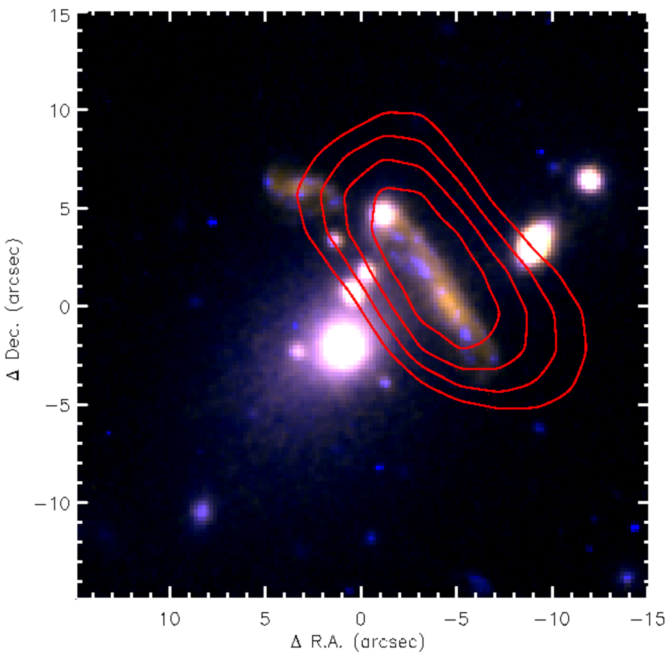


Figure 1: One of the clusters observed as part of the S2LS survey, in which we detect resolved 450 μm emission from a z=1.0 arc seen through the cluster Abell 521. The red contours represent 450 μm signal-to-noise at 3, 4, 5, 6-σ, and are overlaid on a true-colour image constructed from HST, F606W and Keck K-band images. Thanks to J. Richard for the Keck image.

Mapping the Galactic Centre

Harriet Parsons (JAC) on behalf of the Staff Time group

In recognition of the effort and dedication shown by observatory staff in commissioning SCUBA-2, the JCMT Board awarded the science staff at the JAC 30 hours of telescope time. The group chose to use these hours to observe the Galactic Centre as a complement to the existing JCMT legacy programme.

Observing Strategy

The data were collected between May and September 2012 in weather with τ(225 GHz) < 0.12. The area was observed using one-degree PONG maps in two rows covering ±5 degree in longitude and ±1 degree in latitude centred on the Galactic Centre. These maps were spaced so that they overlapped by a third of a degree in longitude. This large region of overlap was selected to allow extra redundancy for the mosaicking programme (WCSMOSAIC in this case) when combining adjacent tiles.

Our final rms across the map is 18 mJy at 850 μm out to ±1 degree in latitude with much of the observed area obtaining a lower rms due to varying weather conditions and occasional repeated observations that were needed.

Our methodology of overlapping PONG observations ensured regions within the map were covered by multiple observations. To date the reduction of the data is providing some promising results (see Figure 1).

Data Reduction

The reduction method used to produce the image is similar to that used by the JCMT Plane Survey (JPS), i.e., using Herschel SPIRE 500 μm data to form the basis of an initial input into the map making process. This, combined with work optimising the parameters used within the map-maker, has resulted in a bespoke configuration file (see page 23 for more details about configuration files and the map-maker).

The reduction of the Galactic Centre data has progressed a long way, particularly with the recovery of the more diffuse emission over larger areas — which still remains non-trivial. Like the JPS, the data from this project will benefit from the upcoming 'skyloop' map-maker technique which is under development (see the JPS article on page 13 for further information).

Legacy Value

This map is a huge step forward from the original SCUBA map of the Galactic Centre (Pierce-Price et al. 2000). They reached an rms of 30 mJy (in contrast to 18 mJy here) and covered an area of just over one deg^2 (in contrast to 20 deg^2).

These Galactic Centre data will not just be complementary to the other JCMT Legacy Surveys but will also be invaluable for astronomers trying to understand massive star formation across the Galaxy. The extreme and unique physical conditions found in this part of the Galaxy result both in a higher rate of star formation and an excess of massive stars compared to the rest of the Galactic Plane. As such this project will be an important addition to the JCMT legacy.

Pierce-Price, D. et al., 2000, ASPC, 217, 164

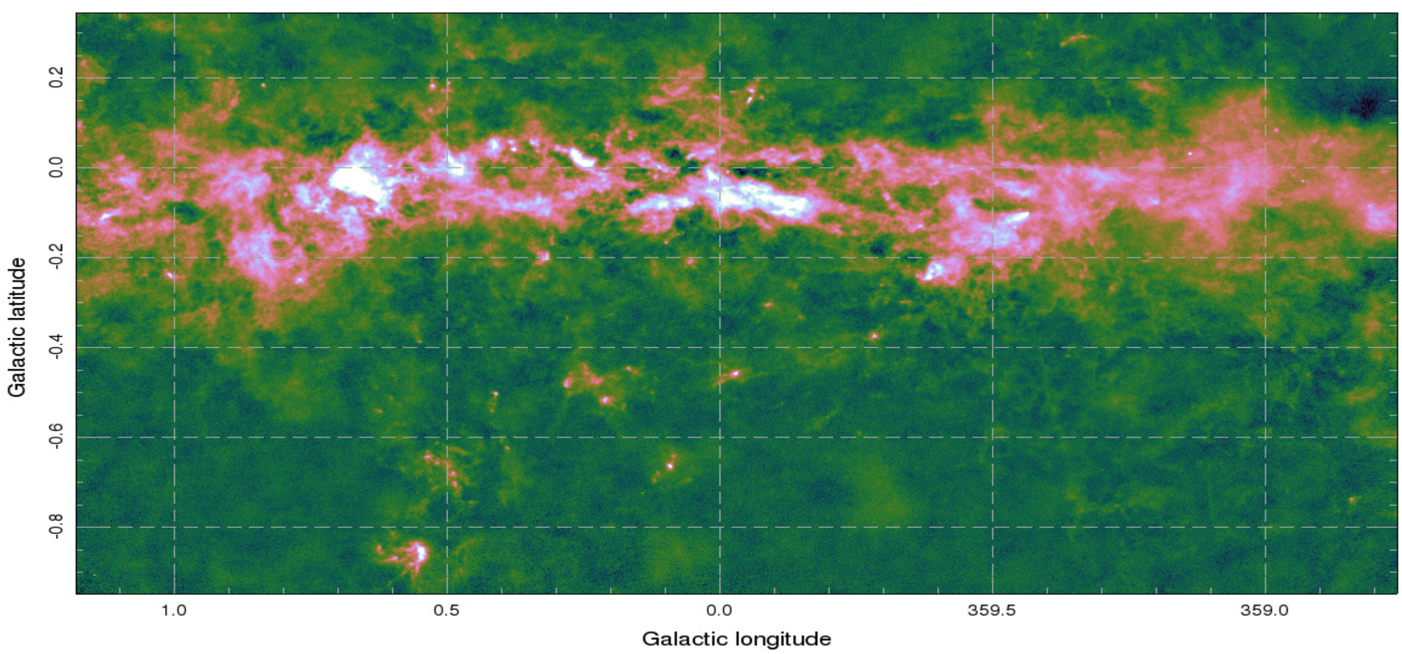


Figure 1: A region of the Galactic Centre map at 850 μm. Observations were taken using overlapping PONG maps. The full area mapped covers 355° < l < 5° and b = ±1°.

"Artificial Intelligence" to Identify Outflows

Harriet Parsons (JAC)

The advantage of being a support scientist is the networking opportunities available with so many astronomers passing through the JAC throughout the year.

One result of this is a collaborative effort to use a machine-learning code to identify outflows in star forming regions observed by HARP. The idea to use machine-learning code to identify features within HARP data cubes builds upon work presented by Christopher Beaumont et al. in a paper entitled: "Classifying structures in the ISM with Support Vector Machines: the G16.05-0.57 supernova remnant" published in the Astrophysical Journal in 2011.

The idea is to train the code to classify each pixel of data above a threshold as one of two types of object: outflow and non-outflow. To do this we provide the code with examples of what we identify an outflow to be within the data and what we identify as part of a cloud. The code then creates feature vectors — vectors that describe each pixel within the data, i.e. the zero, first and second moments of the data in a small region around each pixel. The code then attempts to look for similarities across these feature vectors for the two distinct object types provided and tries to classify them accordingly. This code is first run against a test data set that has previously been categorised by eye. This provides a means of assessing the reliability. Finally the code can be run on the full data set.

Fundamentally this method of machine learning does not remove the question of what is the formal definition of an outflow — a question open to further discussion. We simply train the code to imitate intelligent human behaviour to make identifications of outflows that the human eye would agree with.

Making this a computerised method provides an enormous advantage in studying outflows: a logical and repeatable method of identification within complex data. It also allows for an easier way to extract these outflow features from the data. Although this work is still in its early stages the potential of this method is highly exciting.

This work is in collaboration with Christopher Beaumont (Institute for Astronomy Honolulu and Harvard Smithsonian Center for Astrophysics) and Lientjie de Villiers (University of Hertfordshire)

Beaumont, C., Williams, J. & Goodman, A., 2011, ApJ, 741, 14

COHRS First Data Release

Holly Thomas (JAC) on behalf of the COHRS team

The COHR (or CO High Resolution) Survey is a long-running project led by the staff at the JAC to map the Galactic Plane in ^{12}CO (3-2). Started as a small project to test the mapping capabilities of HARP in the poor weather bands [τ(225 GHz) > 0.12], it evolved into a multi-semester PI programme which has now mapped over 25 deg^2.

The survey area currently extends in longitude from 10° to 55°, and in latitude to ± 0.5° for 10° < l < 17° and ± 0.25° for 17° < l < 55°. Current observations are expanding the latitude range to ± 0.5° for the full survey area and to extend the maximum longitude to 65°.

This region was initially selected to maximise the overlap with existing and future surveys. Complementary data is of prime importance when dealing with often optically thick CO emission.

Data Reduction

The reduction process has been a long task and was made particularly challenging by the strength of CO in the inner Galactic Plane. With emission almost everywhere, the difficulty arises in finding line-free baseline regions.

The data has been run through the ORAC-DR pipeline using the improved baseline fitting algorithms introduced in the most recent Starlink release (Kapuahi). This improved technique adds intermediate steps which look for high and low frequency ripples which would otherwise not be successfully fit by a standard polynomial (see page 24).

Data Release

The COHRS project has a dedicated VOSpace at CADC/CANFAR from which the data products can be accessed. This VOSpace will be made publically accessible within a few weeks.

We will be offering the data in various formats:

(1) Reduced cubes smoothed to 1 km/s velocity resolution.

(2) Integrated intensity maps — cubes that have been collapsed spatially to include all emission above 3 σ.

(3) L-V maps — cubes collapsed over the latitude and the velocity axis (from -60 km/s to 125 km/s).

The data will be available in 0.5° width tiles (in longitude) and will be named for the central longitude. The latitude range available for any given tile will depend on the data taken to date. Initially, only around 25 % of the tiles will extend in latitude to the full ± 0.5°. Details will be given in an accompanying README file, which will be updated as new data are incorporated into the reduced tiles.

Watch the JCMT webpages for updates.

Reducing SCUBA-2 Data

Holly Thomas (JAC)

Article based on the SCUBA-2 Data Reduction Cookbook, (Sept. 2012) — www.starlink.ac.uk/docs/sc21.htx/sc21.html

The Map-Maker

SCUBA-2 data reduction is carried out by the Dynamic Iterative Map-Maker (DIMM), hereafter called the map-maker. The map-maker completely automates the reduction of your observations from un-cleaned raw data to science quality maps. It works by modelling and removing the different contributions that make up the signal detected by each bolometer. The idea is that it will separate the noise from your astronomical signal.

The first stage of the reduction is the pre-processing step. Here, raw data is cleaned and the flat-field correction is applied to calibrate the bolometers.

Next comes the iterative stage. The first components to be fitted and removed are the COM and GAI models. The COM model represents the average signal from all bolometers (common-mode) which is then subtracted. GAI (gain) is an offset that scales the bolometers to the same level.

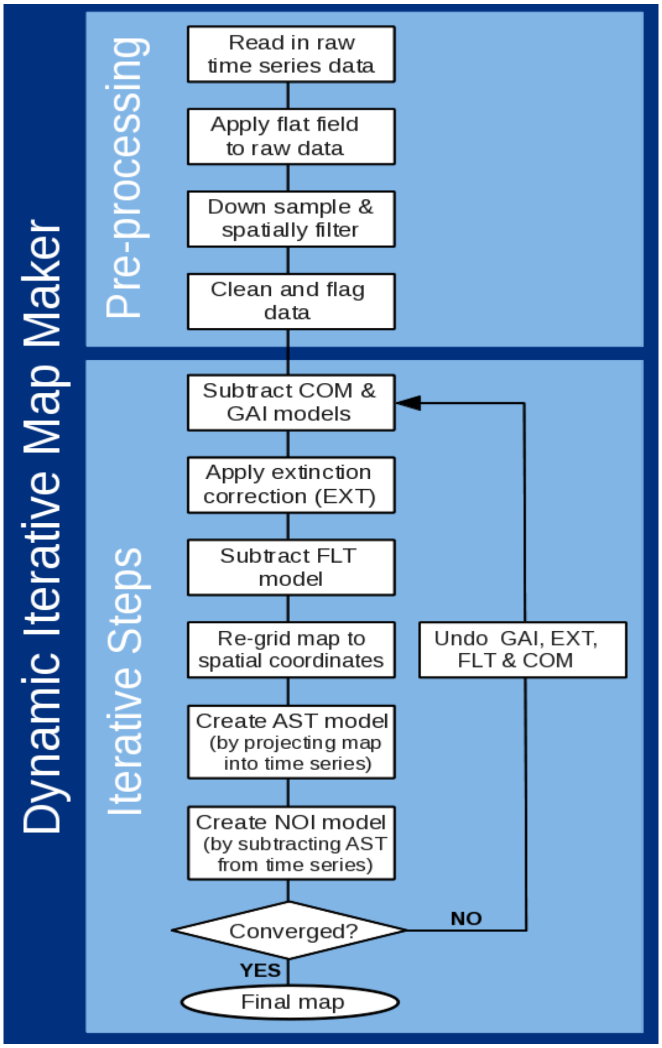
The next step is the application of the extinction correction, or the EXT model. This is a time-varying scale factor that is derived from the JCMT water-vapour radiometer. Following this, a Fourier transform is applied to the data and the FLT (filter) model is applied in the frequency domain. This is designed to remove the low frequency $1/f$ noise from the data.

Once these models have been removed, the data is regridded to produce an estimate of the final map. The astronomical signal determined from the spatial map is then projected back into the time-series; this results in the AST (astronomical) model for the bolometers as a function of time. The NOI (noise) model is calculated at the end of the first iteration from the FFT of the residual between 2 and 10 Hz. NOI is not subtracted but is used to weight each bolometer for successive iterations.

After the second iteration, the convergence is checked. Convergence is achieved either when a specific number of iterations have been completed or when the models have changed by less than a specified convergence criterion. If convergence is not achieved, the COM, GAI, EXT, and FLT models are undone and are re-evaluated during the next iteration only with the previous estimate of the AST model already removed.

Configuration Files

An external configuration file must be supplied to the map-maker which details the requirements for the data cleaning and the iterative parameters. Specialised configuration files may be selected depending on the science goals of your data, be these extracting faint extra-galactic sources or recovering large scale extended structure in the Galactic Plane.



Flowchart illustrating the map-maker process.

Tailored configuration files are essential to getting the most from your data. Currently there are 3 that are released with the Starlink package: 'bright and compact', 'extended' and 'blank-field'. Refer to the full sc/21 manual for more details on these recipes and their implementation.

Minimum Computing Requirements

To run the map-maker effectively on a single typical observation we recommend a minimum of 64 GB of memory. A machine with less memory can be used but will usually produce inferior maps due to the data being split into smaller chunks. The time taken to produce the map depends on the number of cores available, however having more than 10 to 12 cores gives little extra benefit due to the time spent on operations that cannot be split between mutliple cores.

HARP/ACSIS Data Lose their Stripes

Malcolm Currie (JAC)

The presence of stripes in the pipeline-reduced products from ACSIS/HARP has long been a source of frustration. The stripes can dwarf the subtle astronomical signal and degrade the measurement of astrophysical parameters. They originate from interference — cables and their connections, electronic pickup, and certain telescope motions are likely sources.

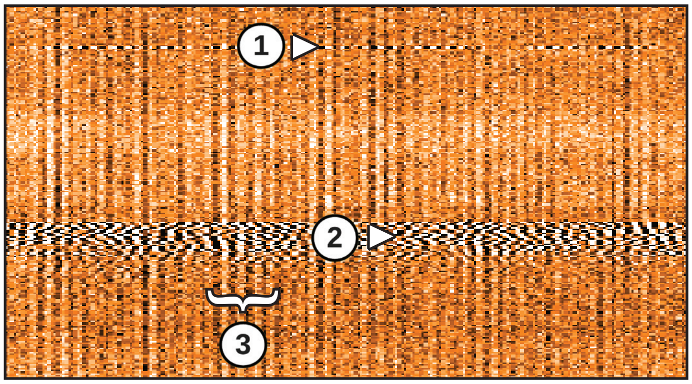


Figure 1: This example of raw data shows all three known high-frequency patterns: (1) single or (2) bands of spectra with amplitudes of 20 – 100 T_A, much stronger than most sources; and between them (3) correlated ringing. Although the ringing is somewhat weaker (peak is <10%), it spans across many spectra giving a similar power.

The interference exhibits a selection of morphologies, which may be divided into two classes: high-frequency and low frequency. The high-frequency noise (see Figure 1) has considerable power and generates the most-obvious artefacts in the reduced cube. Although the low-frequency ripples are less intense than the high-frequency forms they can also have pernicious, but not always blatant, effects upon line strengths from uneven baselines. They tend to occur in time-series blocks, but can apply to all spectra for a receptor. They have a wide range of morphologies such as sinusoids, irregular ripples, and curved car headlight-like beams that start strong but gradually pan out and fade with time.

While most affected spectra can be identified visually and flagged as bad, say with KAPPA:CHPIX or GAIA, it is tedious and can be subject to errors of omission. This is because some of the interference is subtle or fine-grained, such as a single spectrum easily missed amongst thousands of spectra for each receptor and each raw time series. Also it has been common practice to exclude whole receptors from the reductions, when in fact only a fraction of the spectra measured with the receptor suffered from an interference signal, thus lowering the signal-to-noise.

A better approach is for the ORAC-DR recipes to identify and flag the anomalous spectra. This has been done for the known types of interference. The details of the algorithms used can be found in the JCMT Pipelines and Archives blog (http://pipelinesandarchives.blogspot.com).

The results are encouraging. While the noise in the final cubes is not quite as low as from meticulous hand-crafted extraction (Walker-Smith priv comm), there is no denying the major improvement in quality from the automated filtering of the interference. Figure 2 shows an example comparison where the data were originally rejected on quality-assurance grounds.

This feature will be available in ORAC-DR as part of the Hikianalia Starlink release (scheduled for February 2013).

Sadavoy, S. et al., 2012, ApJ, submitted

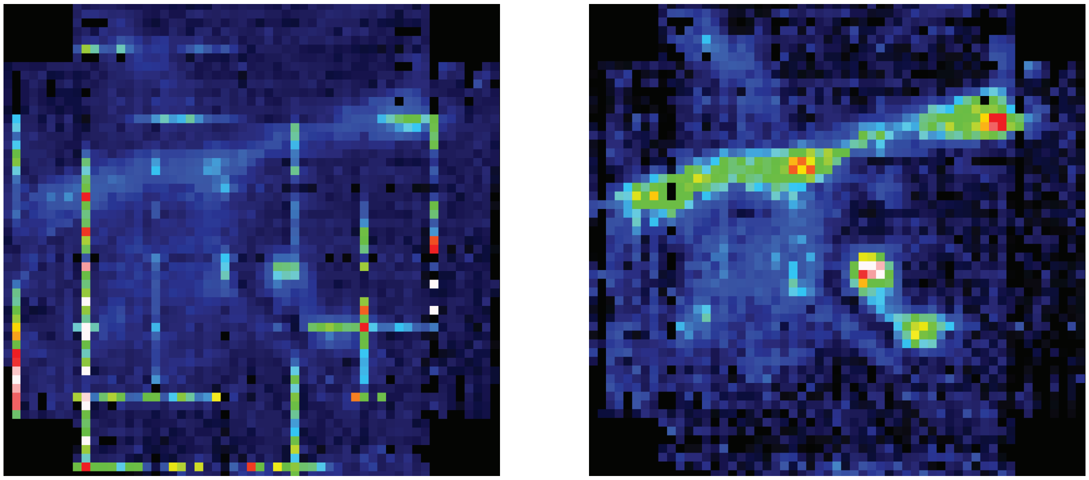


Figure 2: Comparison of ^{12}CO 3-2 integrated intensity maps in Perseus B1 from Sadavoy et al. (2012). (Left) A map made with the previous reduction pipeline. (Right) A map made from the same data after implementation of the interference filtering.

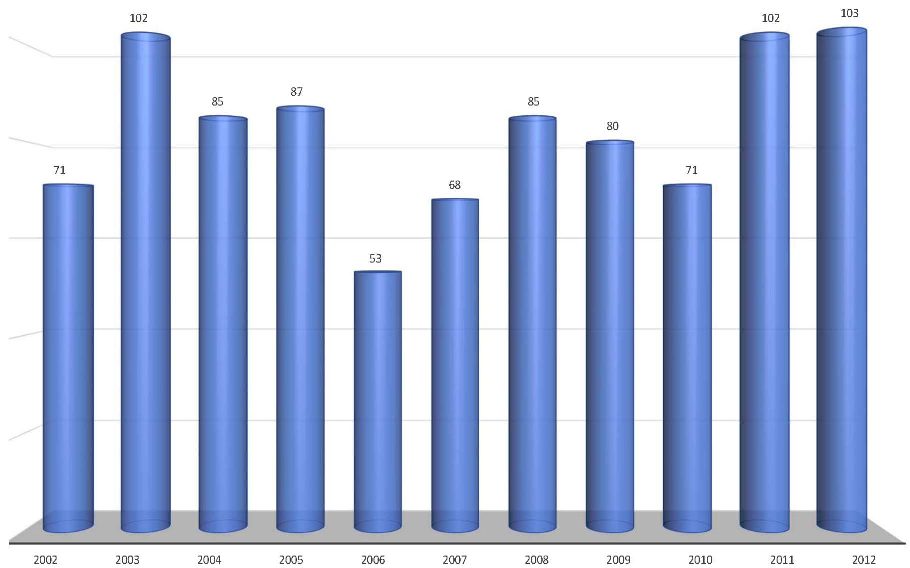
Observatory News

Holly Thomas (JAC)

JCMT Publications Hit a Century Again

Like all observatories the JAC tracks the number of published scientific papers that are based on data from our telescope. This is conveniently used as a measure of our productivity. At the JCMT we are delighted that, despite its uncertain future, the JCMT is breaking its own publication records.

In 2012, the JCMT has set a new record with 103 publications, beating the previous best of 102 set in 2011 and 2003. The 2003 numbers however were set during the peak of SCUBA's productivity. This recent performance is especially impressive considering the focus on commissioning and on-sky testing of SCUBA-2 prior to 2012. We look forward to equally good numbers in 2013.

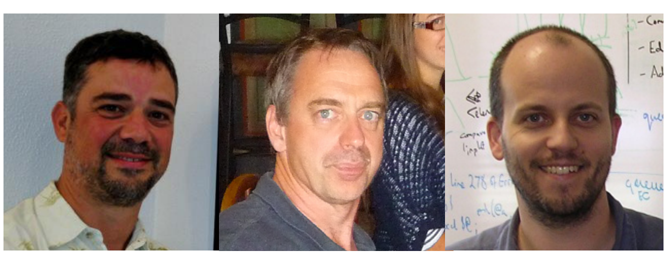


A record of JCMT publications over the past decade.

Arrivals and Departures

Over the last couple of years we have said a parting aloha to some good friends, but have had the pleasure of welcoming some new ones.

We have said a fond farewell to Antonio Chrysostomou (Science), Jeff Cox (TSS), Simon Craig (Engineering), Chris Davis (Science), Linda Fisher (Admin), Tim Jenness (Scientific Computing), Russell Kackley (Computing), Jonathan Kemp (TSS), John Kuroda (Engineering), Mark Millard (Admin), Luca Rizzi (Science), Erik Starman (Engineering), Jean Stoner (Admin) and Remo Tilanus (Science).



Familiar faces that have left the JCMT. From left: Antonio Chrysostomou; Remo Tilanus; Tim Jenness.

Antonio had been Associate Director of the JCMT since 2005. He was, and remains, heavily involved in the legacy surveys and will be sorely missed. He has now returned to the University of Hertfordshire, from where he was on leave, as a Reader in Astrophysics.

Remo served as Head of Operations at the JCMT for the past decade. He knows this telescope as well as anyone and his expertise will be difficult to replace. Luckily he remains engaged in JCMT activities, especially VLBI science. Remo left to take a post in the Netherlands at Leiden Observatory as Programme Manager of ALLEGRO, the local ALMA Arc node. He will also spend some of his time at the mm-VLBI group of the Department of Astronomy at Radboud University in Nijmegen.

Tim Jenness had worked at the JAC since 1995. Amoung his many achievements, Tim pioneered the ORAC-DR pipeline and created the Observatory Management Project (OMP) which introduced all of us to the MSB. He has gone on to become Head of the Computing Division at CCAT. The JAC retains Tim's knowledge through a consulting arrangement.

We are delighted however to welcome a number of new staff members: Mark Ayap (Engneering), Graham Bell (Scientific Computing), Daniel Berke (Science), Ryan Berthold (Computing), Jamie Cookson (Engineering), Doug Johnstone (Associate Director), Donna Kim (Admin), Callie McNew (TSS), Will Montgomerie (TSS) and Harriet Parsons (Science). In addition, a few former employees have returned to us: Malcolm Currie (Scientific Computing), Wendy Light (Admin) and Ian Campbell (Engineering).

Outreach Activities

Harriet Parsons (JAC)

On the Water Hawaiian-Style


A few members of the paddling team enjoying the sunshine.

Waves and fluids was a topic taught in the final year of my undergraduate degree. But distant memories of Reynolds numbers and Bernoulli's principle offered little help when I volunteered to coax, coach, and captain a JAC entry in the 29th Annual Kamehameha Business Outrigger Canoe Regatta.

This charity event, held in Hilo Bay, pitted local businesses against each other in various categories from the uninitiated to the seasoned paddler. Software engineers, mechanical engineers and support astronomers, helped out by friends and family, formed the three crews entered by the Joint Astronomy Centre. Paddling ability was also diverse with mostly complete novices, a few recreational paddlers and a couple of competitive paddlers. This range of abilities proved somewhat challenging and meant that our two crews in the intermediate division had at least one paddler with less than two hours of previous experience on the water!

Practice, although brief, went well with everyone grasping the basics of technique, commands, and timing. As race day came, most were surprised to find out what a big community event this was. The full stretch of Bayfront was covered in team tents and people selling shaved ice, hot dogs and spam musubi. The rain clouds that usually dominate Hilo skies stayed away, adding to a great atmosphere.

Everyone paddled hard but after the first race all crews ended up in the aptly named 'hana hou' (again) division, specially designed so that crews that did not finish top still had a chance to paddle at least twice. This division proved slightly more successful for the intermediate women who went on to reach the semi-finals.

Despite the lack of silverware making its way back to the JAC the event was a success with good support for our observatory from fellow teams and organisers. There is always next year… hana hou everyone!

Foodbank Fundraising

A few of the observatories join forces every year to participate in a charity softball tournament. Organised to raise money for the Hawaii Island Foodbank, this tournament brings in volunteer teams from organisations across the community — from astronomy to sanitation to individual families.

Last year the observatory team, calling themselves the "All Stars," raised $600 through their efforts. The team was organised by Craig Walther from the JAC, who led a very mixed group of abilities onto the field. Although our success on the field was limited, everyone had a good time and were happy knowing it was all for a good cause.

In the separate JAC Food Drive, staff at the JAC collected 168 lbs of food and raised $175 though staff donations in 2012. Indeed, over the past decade the JAC has raised 1200 lbs of food and nearly $1000 for the Foodbank.

Collections for the Foodbank appeal in the JAC break room.

Reaching Out: Astronomy in the Community

JAC team members at AstroDay 2012.

Here in Hilo, more than most places, there is a real need for astronomy outreach — connecting the observatories directly with the local community. Mauna Kea, which stands at 14,000 feet, is the reason the observatories are located here. Mauna Kea is also known as Mauna O Wakea; according to Hawaiian mythology this is the mountain of the god Wakea, the god from whom all things in Hawaii are descended. For Hawaiians and visiting observers alike, this mountain is more than myths and legends, it feels special.

The JAC has seen a successful year of participation in outreach. Journey Through the Universe — a programme that places astronomers directly into school classrooms — was very well received. Staff from the JAC volunteered their time to teach astronomy to all ages, from kindergarten to high school, over the course of a week. Lessons included understanding the concept of radar (to map the surface of Venus), planetary motion, and getting to grips with the scale of the Solar System and beyond.

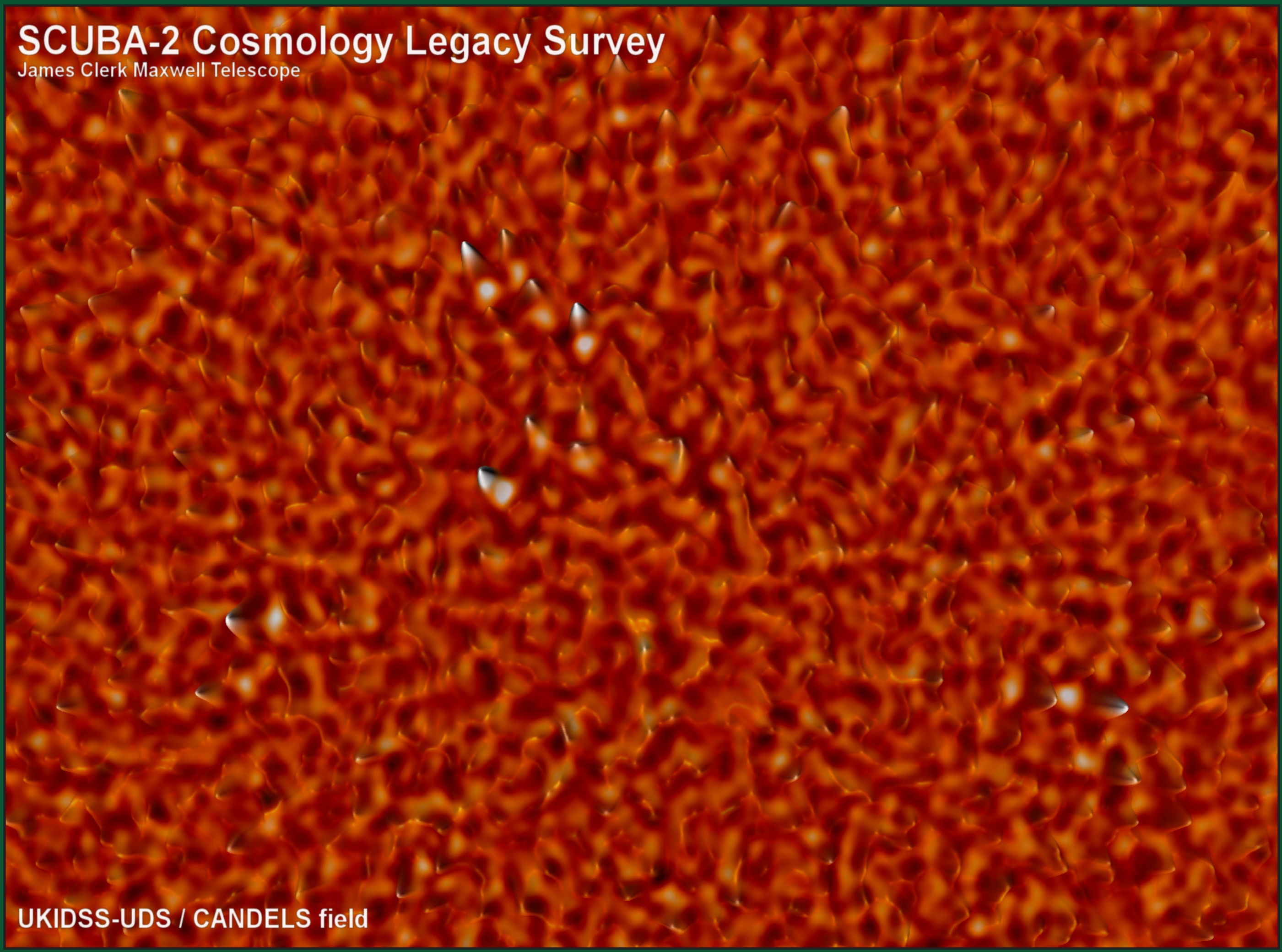
This last activity is traditionally one of the most enjoyable, involving nothing more than the humble toilet roll — a cheap, hands on, engaging, humorous and easily obtainable outreach tool! Students use it to learn about the astronomical unit: with one sheet of toilet paper equivalent to one AU. Thirty sheets are needed to reach Neptune from the Sun, and if you decide to go for Pluto you suddenly find the classroom is not as big as you thought it was!

The other major outreach event for the year by JAC staff was AstroDay. This event, held annually in April at the mall in Hilo, sees all the observatories on Mauna Kea come together and provide activities and giveaways for the public. Coinciding with the JCMT's 25th anniversary, the JAC had plenty to keep families entertained and gave away 200 birthday balloons. The science highlight was a 7-foot tall 3D Orion constellation to illustrate the concept of relative star positions. Especially popular with the younger kids were the stellar face painting and free JCMT and UKIRT snow globes!

Alongside these main activities staff have given talks and hosted planetarium shows at 'Imiloa Planetarium, raised money for breast cancer research and the Hawaii Foodbank, and supported the County Science Fair and a local children's astronomy/art coin design contest. Altogether a good year!

Celebrating 25 years of science with the JCMT

The current suite of instruments on the JCMT. Image released to celebrate our 25th birthday in April 2012. (From left to right): SCUBA-2 camera; Holography receiver; Receiver A; the Water Vapour Monitor; Receiver W; HARP on the right Nasmyth platform; and ACSIS, the backend spectrometer for the heterodyne receivers.



JOINT ASTRONOMY CENTRE
JCMT UKIRT