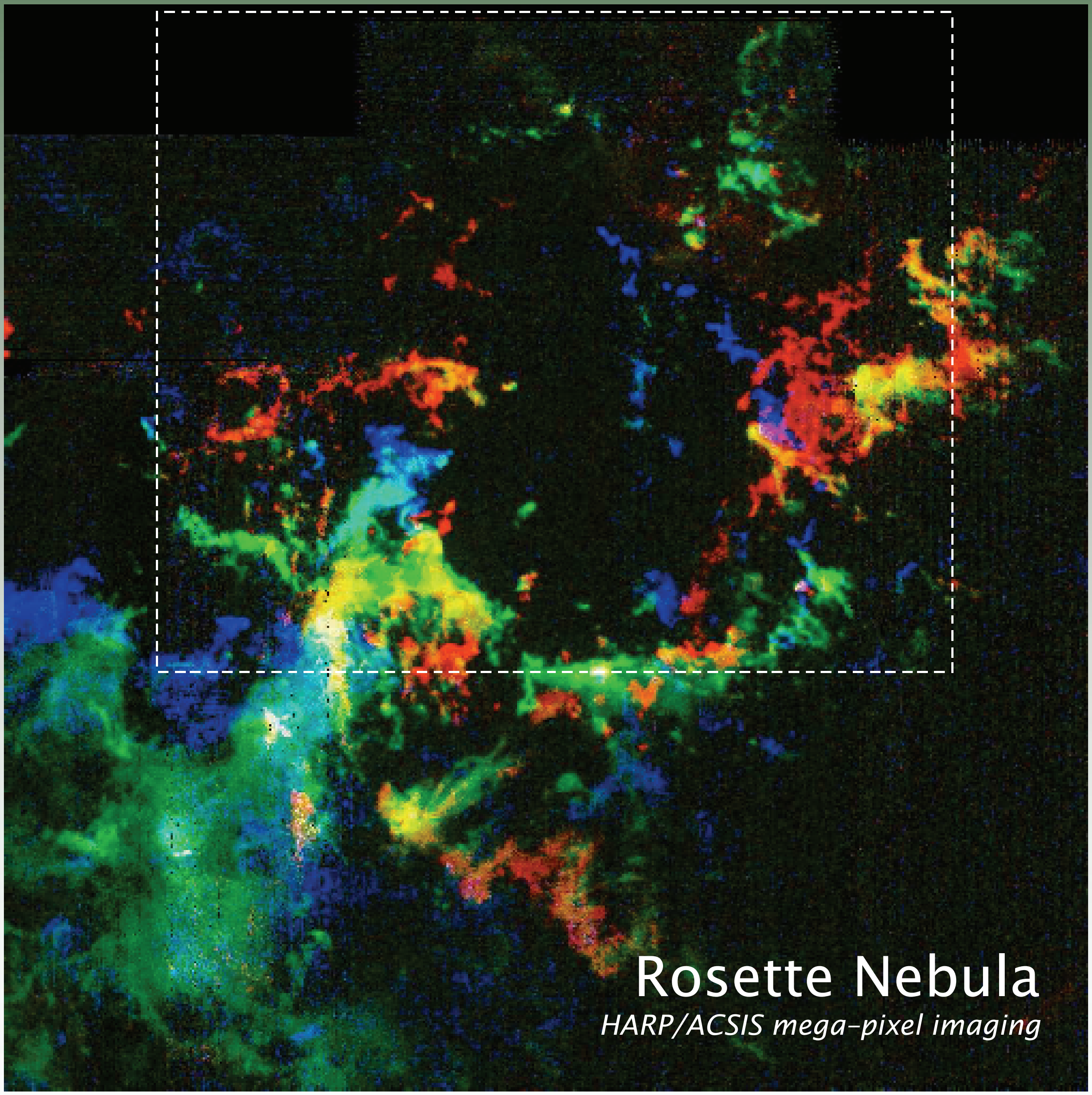
JCMT Spectrum

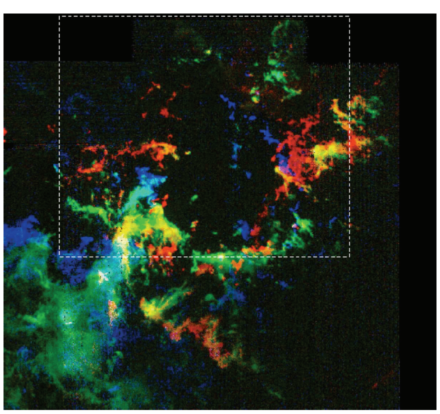
Newsletter of the James Clerk Maxwell Telescope

Spring 2007 · #26

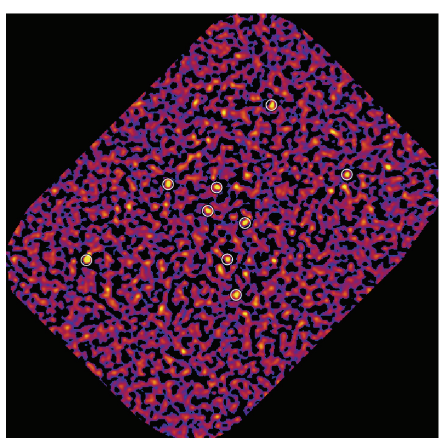


Early HARP Results

In This Issue



On the front cover: ^{12}CO J=3–2 emission toward the Rosette Nebula. The image is ~2.5 deg across. Integrated emission over three velocity ranges is displayed as red (15.7–25 km/s), green (11–15.7 km/s) and blue (-3 – 11 km/s). (Also see Figure 1 and article on page 5 of this issue for more information.)



On the rear cover: AzTEC 1.1 mm map of the full 10 × 16 arcmin GOODS-N field. All 9 sources with S/N>5σ are circled. (Also see Figure 1 and article on page 6 of this issue for more information.)

JCMT Spectrum, Newsletter of the James Clerk Maxwell Telescope, is published biannually and is edited by Gerald Schieven and Jonathan Kemp.

ISSN 1351-5497.

postal address
James Clerk Maxwell Telescope
Joint Astronomy Centre
University Park
660 North A`ohoku Place
Hilo, Hawai`i 96720-2700
USA

telephone
+1 (808) 961 - 3756

facsimile
+1 (808) 961 - 6516

world wide web
http://www.jach.hawaii.edu/JCMT/

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

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

The JCMT is a member of the RadioNet consortium.

From the Desk of the Director

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

Gary Davis, Director JCMT

Welcome to the spring 2007 edition of *Spectrum*. After the bumper edition of June 2006, the biannual schedule has been reinstated and *Spectrum* has returned to a more normal size. This issue contains a set of articles on results from the AzTEC run on the JCMT in 2005/06, some of which were also presented in a special session at the AAS in January. There are also some articles containing early results from HARP, about which more below.

From a management perspective, the major news of the period was the appointment of an Associate Director for the JCMT, Antonio Chrysostomou. The creation of this position is one component of a larger rearrangement of the JAC senior management, motivated by two factors: first, the need for additional management effort on the JCMT side to implement the JCMT Legacy Survey programme; and second, the need for the Director JAC to split his time more equitably between JCMT and UKIRT than has been the case in the past. The solution, in simple terms, was to split the Director's job into two parts, one to deal with high-level issues on both telescopes and the other to focus on the JCMT. The Associate Director's specific brief is to deliver the science programme of the observatory.

The JCMT is in the midst of an extremely ambitious programme of development in which the entire instrument suite is being replaced. Enormous progress has been made since the last *Newsletter* in the commissioning of the new heterodyne system. The HARP/ACSIS combination was made available to users during semester 06B on a shared-risk basis, and its diagnostic power as the JCMT's first spectral imager (and the first in the world in the 345-GHz band) has been stunningly demonstrated. Some articles in this *Newsletter* attest to this and a press release to announce this new capability is in preparation as we write this column. On four nights in December, the volume of raw HARP/ACSIS data acquired exceeded the volume of all heterodyne data previously taken at the JCMT! We anticipate final acceptance of HARP before this *Newsletter* is issued, and with this expectation HARP/ACSIS has been offered to the community on a common-user basis for 07A.

The flagship of the development programme is, of course, SCUBA-2. A memo was issued to the community on 21st February describing the status of the project. In summary, a number of technical issues have constrained progress, as is only to be expected in a high-risk technical project. Solutions are in hand for all of the issues which have been identified and the instrument is on course for delivery to Hawaii this summer. Two science-grade arrays (one at each wavelength) will be installed before the instrument is mounted on the telescope, and commissioning is expected to take until the end of 2007. There will then be a period of observations with the reduced instrument before the remaining six arrays are installed in spring/summer 2008.

Whilst HARP/ACSIS and SCUBA-2 are expected to dominate the usage of the telescope for several years, three ancillary instruments are also in various stages of development: ROVER, a polarimeter for use with HARP and RxA; POL-2, a polarimeter being developed at the Université de Montreal for use with SCUBA-2; and FTS-2, a Fourier transform spectrometer being developed at the University of Lethbridge, also for use with SCUBA-2. The ROVER hardware has been delivered but significant software development is required; this instrument will therefore be commissioned as time allows amongst our higher-priority commitments. Because the latter two instruments can only operate in conjunction with SCUBA-2, they will not be available until 2008.

Antonio Chrysostomou, Associate Director JCMT

The advent of new instruments with extremely high data rates and the prospect of numerous surveys led to the JCMT Science Archive project, a collaboration between the JAC and the Canadian Astronomical Data Centre (CADC). Russell Redman provided a thorough description of this development in the previous issue (see `http://www.jach.hawaii.edu/JCMT/publications/newsletter/n24/jcmt-n24.pdf`). The first phase of the project, in which raw ACSIS data cubes will be delivered to observers via the CADC, is scheduled for completion before this *Newsletter* is issued. This will be a major milestone involving a huge amount of work at both sites. The second and final phase will enable the generation and delivery of advanced data products (catalogues, maps, etc.). The JCMT Data Users Group (JDUG), comprised of representatives from the survey teams and chaired by the Associate Director, has been restarted to provide user input to this critical project.

The JCMT Legacy Survey programmes are due at last to begin collecting their first photons using HARP in the summer months of 07A. This will be preceded by a Science

(Director's Desk, continued on page 4)

Data Archive at CADC

Frossie Economou
(*JAC Software Group*)

An integral part of our Observation Management Project (OMP) is the ability for PIs and CoIs to retrieve the data from their project within a few hours of their acquisition at the telescope. Since approximately March 7, we have been servicing OMP data download requests through our OMP interface with the Canadian Astronomical Data Centre (CADC) in Victoria. For the time being, this means that during the data download (*i.e.*, as soon as they begin to download non-calibration files), users are prompted for their CADC username and password. This is different from the OMP username/password, and must be applied for directly through the CADC website at `http://hia-iha.nrc-cnrc.gc.ca/cadc/main_e.html` .

For access to proprietary files, each user's CADC username *must* be linked to their OMP user ID, since that is how the system knows that they are entitled to data from a particular project. All JCMT users (PIs and CoIs) who have past or current projects should let their "Friend of the Project" know their CADC username so that it can be inserted into the OMP system.

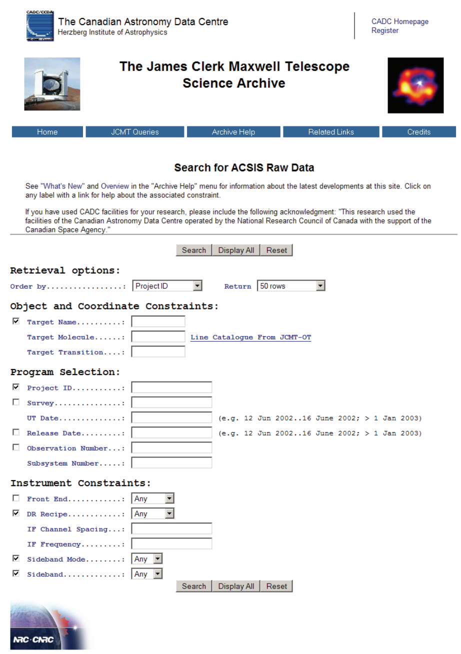


Figure 1. — The CADC 's JCMT Science Archive search interface for raw ACSIS data.

(Director's Desk, continued from page 3)

Verification phase in late April-early May. Representatives of survey teams whose programmes contain HARP components will visit Hilo to work with the JAC in establishing quality control procedures for their surveys. These procedures will then be embedded within the pipeline so that survey managers can make quality assurance decisions on survey data following each night's observing before those data enter the Science Archive.

Our ongoing work to develop an interferometric capability at 345 GHz, in collaboration with the SMA and the CSO and called the eSMA, continues to make good progress. The conversion of RxW for dual-polarisation use in B and D bands is now complete and the instrument is being re-commissioned as we write. We anticipate issuing a Call for Proposals this summer for an eSMA pilot programme, and in order to prepare the community for this opportunity, a very successful workshop was convened in Leiden in February.

Some of you will know that the agreement between the three agencies which provide operational funding for the JCMT has a break point in 2009. Following the highly-successful review of the observatory in 2005 by a panel chaired by Martin Harwit, and in order to fully exploit the investments which have been made in SCUBA-2 and the other developments, all three agencies have indicated their wish to continue funding the JCMT until at least 2012. A formal agreement to this effect is under discussion and it is hoped that a final announcement on this issue can be made within the next few months.

Finally, there are a few staffing changes to report since the previous *Newsletter*. Jamie Leech, who was a key figure in the heterodyne software development, returned to the UK in June 2006. He was replaced in two ways: first, Walther Zwart was recruited in November as a software engineer, having previously worked on the LOFAR project in the Netherlands; and, second, Jan Wouterloot took over from Jamie as the scientific custodian of the heterodyne data reduction system. Jessica Dempsey was recruited as an Instrumentation Scientist and will start at the JAC on 1st April. She will work under the Head of Instrumentation, Per Friberg, to provide operational support for the heterodyne instrument suite.

First Submillimetre Mega-Pixel Image from HARP/ACSIS

Bill Dent (*UKATC*), Gary Hovey, Peter Dewdney, Tom Burgess, John Lightfoot, & Tony Willis (*NRC/DRAO*)

The colour image (see Figure 1 and front cover) shows ^{12}CO J=3–2 emission from the region in and around the well-known Rosette Nebula, taken using HARP/ACSIS in Dec 2006 and Feb 2007. The observations required about 20 hours of fast raster-scanning. The frame is 2.5 deg across, contains ~10^6 spatial pixels, and has been truncated to 70 spectral channels in order to fit into the reduction computer memory. We have displayed integrated emission over three velocity ranges, in red (15.7–25 km/s), green (11–15.7 km/s) and blue (–3 – 11 km/s), to illustrate the complex "3-D" structure in the region. Figure 2 shows the optical picture of the region indicated by the dashed rectangle in Figure 1 (optical image taken by Dave Malin at the UK Schmidt Telescope).

Most of the emission in ^{12}CO is from the Rosette Molecular Cloud (RMC), and extends over 2 deg (or 60 pc). The region around the optical nebula is filled with compact clumps; at larger distances there are several regions of highly extended faint smooth emission. Some well-known bright young stars are obvious, including GL 961 — the bright source to the lower left (which appears as a white/green cross on Figure 1). For the first time we can see the bipolarity and full 2 pc extent of the highly-collimated jet from GL 961. There are also many bright-rimmed clouds in and around the central CO cavity, some of which have associated IRAS objects as well as new outflows, indicating the presence of embedded young stars. Perhaps equally interesting, however, is that many of the bright gas clumps do *not* have embedded stars. Two or three of these have been studied before, but this is the first time that the whole ensemble of clouds around the central Nebula has been observed in such detail.

Even a quick look at the data has turned up several new and interesting features. Comparison with the visible image shows that the dark optical lanes and so-called "cometary globules" are in most cases associated with blue-shifted gas. This gas must lie in front of the Nebula, and has been driven towards us by the stellar UV flux from the luminous central stars. Closer inspection shows that most of these clumps have a velocity shift along their length, ranging from 0.5–3.4 km/s / pc, implying acceleration away from the core. By contrast, most of the red-shifted clumps have no equivalent dark lanes, but show acceleration away from the core in the opposite sense — so they are being driven away on the far side of the nebula. Clearly the O stars in the centre of the Rosette have affected much of the central region of the RMC. By contrast, however, the regions of smooth CO emission are likely to be the undisturbed cloud. We are in the process of investigating other differences between these two regions.

There are also some odd structures for which we do not have a clear explanation at present. One is seen to the SSE of the RMC. An IRAS source is associated with a bright CO clump, presumably a young star; but extending up to 6 pc from this core are several extremely well-collimated streamers of emission. Their line profiles are very narrow (<1 km/s width), which suggests they are not simple outflow jets. They may be magnetically-confined regions of the cloud. The second feature is a peculiar dark lane seen in silhouette against the weak background cloud, appearing to emanate from the region of GL 961, perpendicular to the outflow. One possible explanation is that this is a very cold foreground cloud. Again it implies a very thin 1-D structure. More work is needed to understand these features.

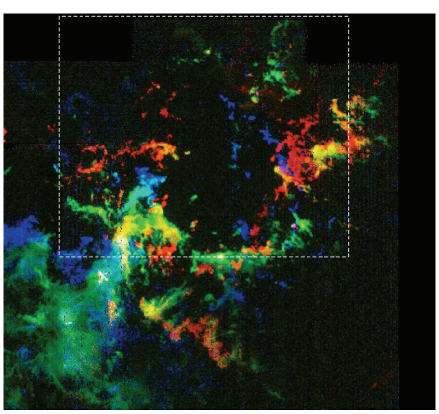


Figure 1. — ^{12}CO J=3–2 emission toward the Rosette Nebula (Figure 2). The extent of the optical image is denoted by the dashed line. The image is ~2.5 deg across. Integrated emission over three velocity ranges is displayed as red (15.7–25 km/s), green (11–15.7 km/s) and blue (–3 – 11 km/s). (Also see front cover of this issue.)

Figure 2. — Optical image of the Rosette Nebula, Sharpless 2–275, courtesy of David Malin and the UK Schmidt telescope. Note the dark "elephant trunks", which are traced by blue-shifted CO emission in Figure 1.

Distant Starburst Galaxies: The GOODS-N Field at 1.1 mm with AzTEC

James Lowenthal (*Smith*), Thushara Perera (*Massachusetts*), Itziar Aretxaga (*INAOE*), Jason Austermann (*Massachusetts*), Edward Chapin, Kristen Coppin, Mitch Crowe, Lisa Frey, Andy Gibb, Mark Halpern (*UBC*), David Hughes (*INAOE*), Glenn Morrison (*CFHT*), Alexandra Pope, Douglas Scott (*UBC*), Kimberly Scott, Grant Wilson, & Min Yun (*Massachusetts*)

Between the demise of SCUBA in early 2005 and eventual commissioning of SCUBA-2 in late 2007, an opportunity opened for another instrument to move millimeter-wave mapping another big step forward: AzTEC, built at the University of Massachusetts by a team including Cal Tech, University of Colorado, UK, Mexican, and Korean partners. Here we briefly discuss some preliminary results from this fortuitous telescope/instrument pairing. (See page 14 of this issue for an AzTEC companion article.)

AzTEC was successfully installed and commissioned at the JCMT in June 2005, and undertook an extensive program of guest observations in November and December 2005. One of those was a set of observations at 1.1 mm (Program C42; PI: Ed. Chapin, UBC) of the entire 10 × 16 arcmin GOODS-N field — which of course includes the much smaller Hubble Deep Field (HDF) targeted by David Hughes and collaborators for 50 hours with SCUBA (Hughes *et al.* 1998), detecting 5 sources with S/N>5. The GOODS-N program was allocated 90 hours in semester 05B, of which about 60 hours of useable data were obtained.

After extensive custom coding and testing of software and reduction, and analysis of the data, the project team has produced a near-final map and source catalog. We believe the JCMT/AzTEC GOODS-N map, with RMS noise 1σ~1.0 mJy/beam, is among the very deepest millimeter-wave maps yet made (see Figure 1 and rear cover). The source catalog includes 9 sources with $S_{1.1}$>4.7 mJy (5σ) and many fainter ones.

Of the nine brightest AzTEC sources, five are also detected by SCUBA, the remaining four all falling in regions where there are no SCUBA data or where the SCUBA map noise is very high. All five have spectroscopic or robust photometric redshifts. The median redshift is z_{med}=3.2, somewhat higher than the z_{med}~2.5 derived for all SCUBA sources (Pope *et al.* 2005). The single brightest AzTEC source, AzGN_0, coincides spatially with the bright GN20 from the SCUBA HDF "Super-Map" (Pope *et al.* 2006), and the combined 850μm and 1.1 mm data provide a strong constraint on the Rayleigh-Jeans tail of the source's spectral energy distribution (SED). To test the robustness of the entire set of AzTEC 1.1 mm sources and to begin to explore their presumably close relation to distant SCUBA galaxies as well as nearby ultra-luminous infrared galaxies (ULIRGs), we stacked the AzTEC map positions corresponding to all GOODS-N sources detected by SCUBA, the VLA 1.4 GHz, and *Spitzer*/MIPS-24μm. In each case, a strong signal with S/N~10 is seen, indicating a strong correlation between 1.1 mm sources and the other bands.

We can use the observed AzTEC sources to construct number counts for comparison to models of evolving galaxy, ULIRG, and AGN populations. In particular, the great depth of the AzTEC GOODS-N map allows the faint end of the number counts to be sampled with greater precision than previously possible.

GOODS-N is the deepest AzTEC "blank" field to date, but not the broadest: AzTEC was also used to map the two SHADES and the single COSMOS fields, as well as fields containing high-redshift radio galaxies, galaxy clusters, and QSOs, as well as several Galactic targets. Results from those projects will be discussed in later issues of this Newsletter, but we will add here that the wide-angle (total ~1 deg²) coverage of the combined fields provides additional bright 1.1 mm sources that help nail down the bright end of the number counts. These sources also provide excellent targets for follow-up with interferometry, such as with the Sub-Millimeter Array on Mauna Kea, which is now being used to pinpoint AzTEC source positions with arcsecond accuracy and to determine how many sources, if any, are blended multiples vs. isolated single sources. Those results will help us characterize and quantify the star formation, galaxy evolution, and AGN properties of the distant dusty starbursts that may dominate massive galaxy formation at z>2.

A special session on *Galactic and Extragalactic Surveys Using AzTEC* was held at the 2007 American Astronomical Society meeting in Seattle in January, where these and other preliminary results from the JCMT 05B run were presented.

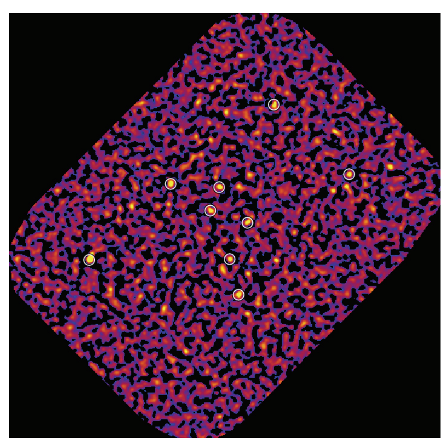


Figure 1. — AzTEC 1.1 mm map of the full 10 × 16 arcmin GOODS-N field. All 9 sources with S/N>5σ are circled. (Also see rear cover of this issue.)

The CMF–IMF Link in Orion

David Nutter & Derek Ward-Thompson (*Cardiff*)

The earliest stages of low-mass star formation are now reasonably well understood. Stars are known to form within prestellar cores in molecular clouds. For a detailed review of this process, see Ward-Thompson *et al.* (2007). However, the formation mechanism for the lowest mass stars and brown dwarfs is less well understood. It has been suggested that these very low-mass objects form by a different mechanism to solar-mass stars (*e.g.*, Whitworth *et al.* 2007 and references therein).

A recent observational result is the discovery that the mass spectrum of prestellar cores mimics the Salpeter-like power-law slope of the stellar initial mass function (IMF) at high masses (Motte, André & Neri 1998). However, due to completeness limits, neither this nor more recent studies have probed the relation between the core mass function (CMF) and the stellar IMF at low masses. Knowledge of this relation is required to understand the formation mechanism of very low-mass stars and brown dwarfs.

In this study, we have combined all of the SCUBA wide-field scan-map archive data taken of the Orion molecular cloud, to produce the deepest and widest-area submillimetre maps ever made of this cloud (see Figure 1). With these data, we investigate the lower-mass end of the CMF.

The data make up four discrete maps, with a total area of approximately 1.5 deg^2. The noise levels in the maps range from 16 to 23 mJy/beam, which translates to a completeness limit of 0.3 to 0.45 $M_\odot$. 392 sources are detected with a peak flux density >5σ relative to the local background.

Mid-IR data for the four regions taken using the IRAC camera on board the *Spitzer* space telescope were retrieved from the *Spitzer* data archive. These data were used to classify whether each core contained a young stellar object (YSO) as described in Allen *et al.* (2004). Submillimetre sources that contain a Class I YSO were removed from our sample to remove protostellar contamination of the pre-stellar core statistics.

The mass of each core was calculated by integrating the 850μm flux density above its 3σ contour. A core mass function was then plotted, which shows a power-law slope at high mass, in agreement with previous studies.

The mass function of the cores is shown in Figure 2. The peak of this CMF lies at 1.3 $M_\odot$. It can be fit with the following 3-part power law which is a canonical IMF (Kroupa 2002; Chabrier 2003) shifted to higher mass, $M\, dN/dM \propto M^{-x}$, where:

$$x = 1.35 \quad (2.4\, M_\odot < M),$$
$$x = 0.3 \quad (1.3\, M_\odot < M < 2.4\, M_\odot),$$
$$x = -0.3 \quad (0.4\, M_\odot < M < 1.3\, M_\odot).$$

This marks the discovery of the turnover in the core mass function for the first time.

The best fit power-law to the low-mass slope of the CMF has an exponent of 0.3±0.2. This is consistent with the low-mass slope of the stellar IMF for young clusters which is observed to lie between 0.2 and 0.4 (Chabrier 2003). If this result is borne out by future observations, then it shows that the CMF continues to mimic the stellar IMF down to very low masses.

The full details of this research can be found in Nutter & Ward-Thompson (2007).

References

Allen, L., *et al.* 2004, *ApJS*, 154, 363

Chabrier, G. 2003, *PASP*, 115, 763

Kroupa, P. 2002, *Sci*, 295, 82

Motte, F., André, P., & Neri, R. 1998, *A&A*, 336, 150

Nutter, D., & Ward-Thompson, D. 2007, *MNRAS*, 347, 1413

Ward-Thompson, D., André, P., Crutcher, R., Johnstone, D., Onishi, T., & Wilson, C. 2007, in *Protostars and Planets V*, eds. Reipurth, Jewitt, & Keil, p. 33

Whitworth, A., Bate, M., Nordlund, A., Reipurth, B., & Zinnecker, H. 2007, in *Protostars and Planets V*, eds. Reipurth, Jewitt, & Keil, p. 459

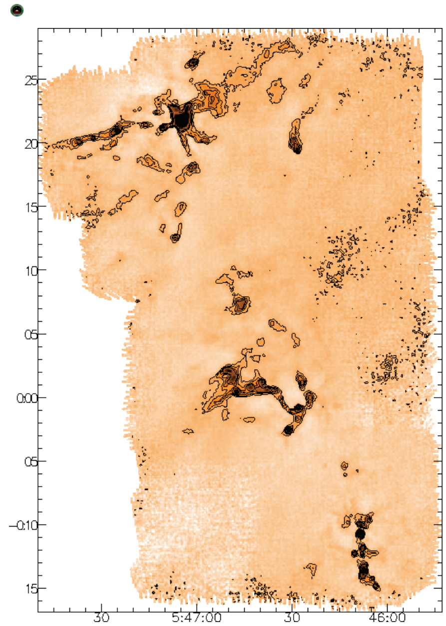


Figure 1. — One of the four maps of the Orion molecular cloud at 850μm.

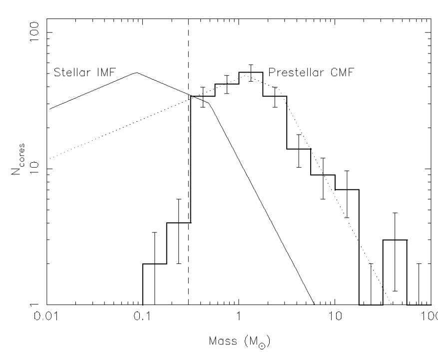


Figure 2. — The core mass function for Orion. The completeness limit is shown as a dashed line. A three-part stellar IMF, normalised to the peak in N of the CMF, is overlaid as a thin solid line. The dotted line shows a three-part mass function with the same slopes as the IMF, normalised to the peak in both N and M of the CMF.

The Circumstellar Environment of the FUor-Like Binary AR6a/b

Gerald Moriarty-Schieven (*JAC/HIA*), Colin Aspin, Bo Reipurth (*Hawaii*), & Gary Davis (*JAC*)

FUors, named after their prototype FU Orionis, are young, low mass protostars undergoing massive (up to 100 fold), temporary (over periods of decades to centuries) increases in accretion producing rates as large as 10^{-4} $M_{\odot}$ yr^{-1} (Hartmann & Kenyon 1985). During these outbursts, FUors experience a brightening of up to 6 magnitudes over a few months, followed by a much slower fading to their original luminosity. For example, the 'classical' FUor V1057 Cygni returned to its pre-outburst state some 35 years after its eruption, while FU Orionis itself has barely declined in brightness in the 70+ years since its discovery. Herbig (1966, 1977) was the first researcher to recognize FUors as young low-mass eruptive variable stars.

Very few FUors have been observed through their outburst phase. The few that have are termed 'classical' FUors and only about ten such objects are currently known. Typical characteristics of FUors include an optical spectrum resembling F- or G-type supergiant stars (Herbig 1977), near infrared spectra similar to cooler K- or M-type giant stars (Mould *et al.* 1978), and an association with bright, often curving reflection nebulae (Goodrich 1987). Many, but not all, possess thermal infrared excess emission and strong sub-mm continuum flux indicative of the presence of massive circumstellar disks and dense, dusty envelopes (Sandell & Weintraub 2001). Some, for example L1551-IRS5, possess significant molecular outflows and Herbig-Haro (HH) flows. Such properties would suggest that FUor events occur during the very early formative stages of a protostar, However, others, for example FU Orionis itself, possess no detectable CO outflow, no obvious HH flow, and little thermal excess and sub-mm continuum emission. This perhaps suggests that such FUors are older and that FUor events are repetitive in nature occurring throughout the first few million years of the star's life.

It is clear, from the numbers of 'classical' FUors found so far, that FUors are extremely rare. The discovery of new candidate FUors is clearly paramount in the study of these early stages of star formation. New candidate FUors, termed FUor-like objects, have been recently found. These are young stars that exhibit many of the unique characteristics of 'classical' FUors yet they were not observed during their eruptive (and definitive) stage. Recently, Aspin & Reipurth (2003) discovered a close double star system in which both components exhibit several FUor-like characteristics. This binary system was designated AR6a/b, and is located near the Cone Nebula (Figure 1) in Monoceros. The NGC 2264 complex, of which the Cone Nebula is a part, is an extremely active region of star formation (*e.g.*, Reipurth *et al.* 2004) and is located at a distance of about 800 pc.

The goal in our investigation of AR6a/b was to estimate the approximate evolutionary stage of this binary FUor candidate. A very young protostar should still possess a large envelope (Sandell & Weintraub 2001) and/or molecular outflow. We therefore used the JCMT to map the region surrounding AR6a/b in ^{12}CO J=3-2 emission, to look for outflow activity, and in HCN J=3-2 emission, to search for dense gas from a circumstellar core/envelope. In addition, we utilized a SCUBA 850 µm map of the region from the JCMT archive at CADC. This was published by Wolf-Chase *et al.* (2003), in their search for dust emission in the region.

In Figure 2 we show the 850 µm dust emission image of the region (*i.e.*, a column density tracer) as a greyscale, with HCN (density tracer) and CO (outflow) contours superimposed. The location of the FUor-like object, AR6a/b, is shown as a magenta dot. Although there appears to be a CO outflow near the location of AR6a/b, the "origin" of the outflow (*i.e.*, center of red/blue lobe overlap) is several arcmin to the west. Furthermore, the HCN core, which overlaps a sub-mm dust core (S6 in Wolf-Chase *et al.* 2003), is not coincident with AR6a/b. Indeed the binary appears to be located toward a local minimum in the density and column density tracers.

The binary does not appear to be

(FUor-Like Binary, continued on page 9)

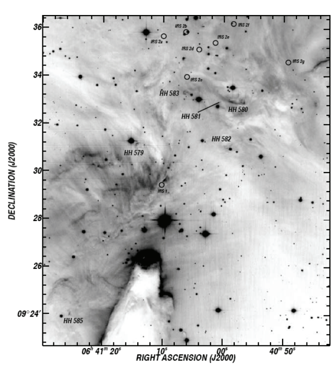


Figure 1. — An optical image (combination of Hα and [SII]) of the region of the Cone Nebula, the most active region of star formation in NGC 2264 (from Reipurth et al. 2004). The FUor candidate AR6a/b is located near IRS2f near the top of the image.

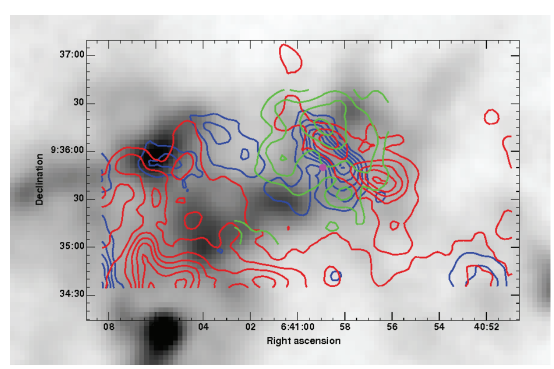


Figure 2. — An 850 µm dust emission (greyscale, from Wolf-Chase et al. 2003) with contours of red-shifted ^{12}CO J=3-2 (red), blue-shifted ^{12}CO (blue), and HCN J=3-2 emission (green) overlaid. The magenta dot at 06:40:59.3, +09:35:52 marks the location of the FUor candidate binary, AR6a/b. Notice that the star is well away from the putative "origin" of the CO outflow, and is located toward a density and column density minimum.

Mapping the W3 Giant Molecular Cloud with HARP

Toby Moore, James Allsopp, Danae Polychroni (*Liverpool John Moores*), Bill Dent (*UKATC*),
Rene Plume (*Calgary*), John Richer (*Cambridge*), Russ Shipman (*SRON*), & The JLS JPS Consortium

In one of the first PI science runs to use HARP (m06bu21), we have mapped the W3 Giant Molecular Cloud in ^{12}CO and ^{13}CO J=3–2 using raster mode. A preliminary ^{12}CO integrated-intensity image is shown in Figure 1. With spatial resolution three times higher than previous CO observations (J=1–0 maps from FCRAO: Allsopp *et al.*, in preparation), the new data show the structures in the molecular gas of this classic star-forming GMC in unprecedented detail. The major luminous star-forming regions (W3 Main, W3 (OH) and AFGL 333) are the bright areas in the eastern portion of the cloud. These regions have formed in part of the cloud compressed by the expansion of the W4 HII region directly to the east, and are a clear examples of triggered star formation. Star formation in the remainder of the W3 GMC proceeds at a significantly lower efficiency.

This project is a pilot study for the JCMT Plane Survey legacy programme (JPS, see the Spring 2006 *JCMT Newsletter* at `http://www.jach.hawaii.edu/JCMT/publications/newsletter/n24/jcmt-n24.pdf`) that will allow us to plan the heterodyne data requirements of the larger Galactic Plane survey. The results will demonstrate whether localised follow-ups of SCUBA-2 detections are sufficient to achieve the JPS science goals or if larger area mapping is required, and help find the best predictor amongst existing data of the ^{12}CO and ^{13}CO J=3–2 distribution in the Galactic Plane. Preliminary inpection shows that the ^{12}CO J=3–2 emission from W3 follows the J=1–0 very closely. The immediate science goal is a census of bipolar molecular outflow activity from young stellar objects in the W3 GMC. This will produce a statistically useful sample of outflows and provide a measurement of the contribution of such outflows to the internal turbulence of molecular clouds.

Figure 1 is orientated with a position angle about +20 deg from true RA–Dec and the x-axis scale of the image is approximately a degree and a half, which is about 60 pc at the distance of the cloud. Figure 2 shows a close-up of the region around W3 Main and W3(OH).

Initial data reduction was done using the HARP/ACSIS pipeline by Brad Cavanagh with Tim Jenness at the JAC. The analysis of these data forms part of the PhD research of Danae Polychroni (Liverpool John Moores University UK).

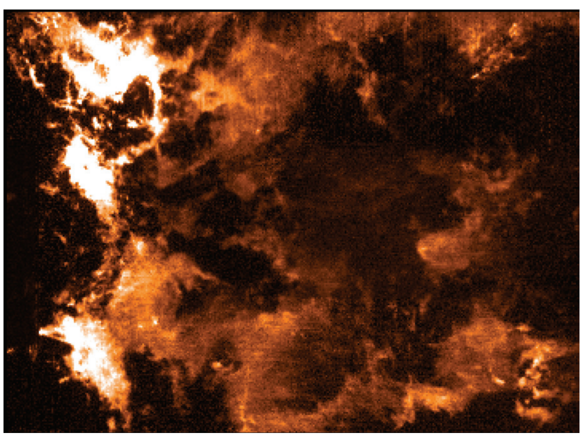


Figure 1. — Preliminary image of ^{12}CO J=3–2 emission toward the W3 Main, W3 (OH), and AFGL333 star forming regions (bright areas on the left side of the image). The image is oriented at a position angle of +20 deg from north, and the horizontal axis is approximately 1.5 deg in extent, or about 60 pc at the distance to this region.

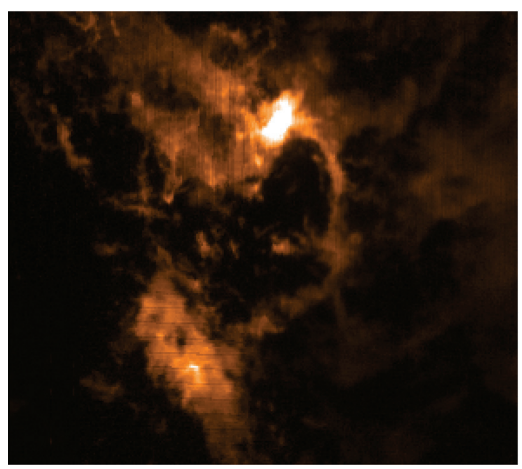


Figure 2. — Close up (approximately ¼ of Figure 1) of the region around W3 Main and W3(OH).

(FUor-Like Binary, continued from page 8)

associated with an outflow, or a large envelope/core. We thus conclude that AR6a/b is a more evolved protostar, more akin to FU Orionis itself rather than to younger Class I protostars like L1551-IRS.

References

Aspin, C., & Reipurth, B. 2003, *AJ*, 126, 2936
Goodrich, R.W. 1987, *PASP*, 99, 116
Hartmann, L., & Kenyon, S. 1985, *ApJ*, 299, 462
Herbig, G. 1966, *Vistas Astron.*, 8, 109
Herbig, G. 1977, *ApJ*, 217, 693
Mould, J., *et al.* 1978, *ApJ*, 222, L123
Reipurth, B., *et al.* 2004, *AJ*, 127, 1069
Sandell, G., & Weintraub, D. 2001, *ApJS*, 134, 115
Wolf-Chase, G., *et al.* 2003, *MNRAS*, 344, 809

Earthquake of 15 October 2006 and the World's Largest Seismograph?

Iain Coulson (*JCMT Support Scientist*)

Sunday, 15 October 2006.

At about 6am, JCMT Telescope System Specialist Jonathan Kemp completed the final observation of a night-shift noteworthy, until then, only for frustratingly poor atmospheric opacity. If the weather had been exceptionally good, or maybe even just a little better, he and the observer, UKIRT Board Chair Gary Fuller, from the University of Manchester, may have been tempted to push on getting data until forced off the mountain by the '14 hour' rule. But the atmosphere was wetter than the blue skies let on, and breakfast at Hale Pohaku beckoned. One last activity could be started before they left, however. The lack of daywork activity on a weekend normally allows several hours of 'inclinometry' to be obtained without disturbance — this allows for routine measurement of the lumps and bumps of the antenna track and for subsequent corrections to the pointing of the telescope. So, following routine, Jonathan closed the carousel roof and doors, started inclinometry, and then left for HP (with Gary). The inclinometry would first run the antenna clockwise, taking tilt measurements from three locations on the antenna every degree or so, then pause and run counterclockwise doing likewise. The antenna is left on auto-pilot throughout the 5 hours or so that this procedure takes. It had worked fine innumerable times in the past. What could go wrong ?

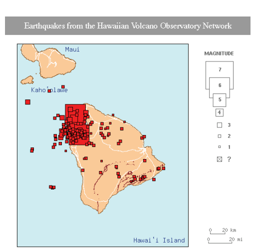


Figure 1. — Epicentre of the mag 6.7 earthquake on 15 October 2006, and aftershocks during the first two weeks. Major aftershocks are indicated. (Image courtesy of United States Geological Survey.)

At about 07:08 HST, 50km west from Mauna Kea, and 40 km below Kiholo Bay, the Earth's crust could no longer take the strain of the ever-increasing load of the Big Island — and cracked. A powerful shock wave shuddered through Hawaii, Maui and Oahu. It shook people out their beds, did substantial structural damage across wide swaths of the islands, and rattled the telescopes on Mauna Kea.

By this time, the inclinometry had rotated JCMT to a position where it was oriented essentially E-W. Inclinometry had been recording the various tilts of the meters every few seconds, a set at each new azimuthal position on its circular course. The data up to that point had been quite normal. Figure 2 shows the tilts from the three tilt meters aligned with the direction of the antenna — now E-W. The irregularities in the antenna track — the targets of the inclinometry experiment — generate structures in these data with amplitudes of a couple of hundred units (mV) or so. However, the tilt meters are also sensitive to acceleration/deceleration so the recorded measures are only necessarily tilts in the absence of accelerations. That's why we move the antenna, wait a few seconds and then make our measurements. Just after the antenna passed through due East (azimuth = 90), the meters went wild — indicating that the tilt meters and the entire telescope had been either seriously tilted, or violently shaken.

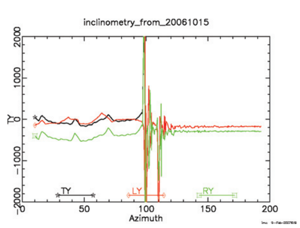


Figure 2. — Output from the inclinometers, used to measure the "tilt" of the telescope, before, during and after the earthquake, until the backup batteries failed. The main mag 6.7 quake is followed a few minutes later by a mag 6.0 aftershock.

In addition to the data recorded every few seconds by the inclinometry, the Telescope Control System also records several telescope parameters with a time resolution of about 1/10th of a second. Among these are the servo errors in azimuth and elevation. These are the differences between where the telescope is commanded to be, and where it actually is. Figure 3 shows the servo errors during the minute or so prior to the earthquake.

The servo works to keep the errors at zero, and high resolution data like these reveal this continual struggle, even when things are proceeding according to plan. Every time the telescope moves in one direction, say, after having made an inclinometry measurement at one azimuth, errors appear — most noticeably in azimuth in this case. The servo commands the telescope to move so as to close the 'gap' and the errors diminish to zero, at which time the telescope is said to be 'on source'. Tilt measurements are made again, and the antenna commanded to its next position. This plot shows particularly well the rhythmic motions of the antenna in azimuth. Three such cycles are seen in the diagram, but at about 07:07:54.5 HST the pattern fails to repeat — the first sign of trouble!

(Earthquake, continued on page 11)

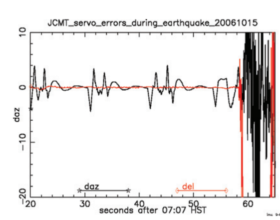


Figure 3. — Output from the servo encoders during the few seconds before and during the earthquake. The azimuth motor servos first indicated "something wrong" at 07:07:54.5 HST, about five seconds after the quake began at the epicentre. About four seconds later, a much more violent event occurred, possibly the arrival of the S-wave.

GAIA 3D: A New Dimension

Peter Draper (*Durham*)

In preparation for some heavy duty work with ACSIS at the JCMT, the Starlink Graphical Astronomy and Image Analysis tool, GAIA, has been considerably enhanced. It is now much faster at displaying image slices, handles FITS cubes as well as NDFs, and now features an all new real-time interactive spectral extraction display, which provides point and region extraction.

GAIA also has new controls for creating channel map images, re-binning and smoothing cubes, capturing animations, creating moment maps, and doing baseline subtraction. On 64-bit platforms, cubes greater than 2 Gb can now be handled. GAIA naturally, thanks to its use of the AST library, has full support for spectral coordinates and can even display raw ACSIS time-series cubes.

GAIA doesn't provide any spectral analysis functions, so to analyse spectra you can send them to the SPLAT–VO application (or you can save them to NDF or FITS and use your favourite package). SPLAT–VO provides facilities for fitting backgrounds, fitting spectral lines (Gaussian, Lorentzian, and Voigt profiles), displaying standard line positions, changing the standard of rest, setting the source velocity, getting simple statistics and filtering, as well as allowing the comparison of many spectra.

The accompanying images and text show some of these features in action.

Obtaining the Software

The latest release of the Starlink Software Collection — the Hokulei (Capella) release — can be found at: `http://www.jach.hawaii.edu/software/starlink/` . Binary releases are available for 32-bit & 64-bit Linux, PPC, & Intel OS X.

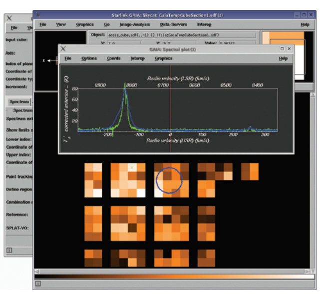


Figure 1. — GAIA extracting a spectrum. Once a data cube is loaded, one can extract a spectrum at a particular position simply by clicking on the pixel. By dragging the cursor around the image, the spectrum from each location is displayed in turn on the same display. One can also display an average spectrum over a circular region, plus many other features.

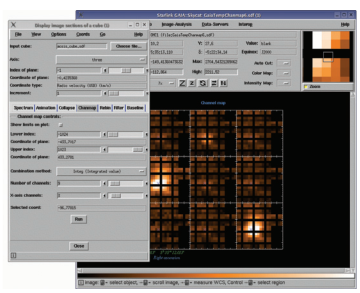


Figure 2. — Using the Chanmap controls: one can create a channel map image of the datacube, i.e., a series of images showing the emission within a sequence of velocity ranges. Other features include creating a Collapse image showing the integrated intensity within a velocity range, or subtracting baselines from all the spectra in the datacube.

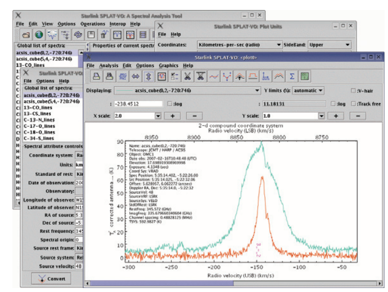


Figure 3. — Inspecting with SPLAT–VO: to inspect spectra in more detail, or measure line parameters, fit models, do simple arithmetic, etc., one can send a spectrum from GAIA to SPLAT–VO. Here we see SPLAT–VO displaying two such spectra and plotting the line identifiers plus a synopsis of useful information.

(Earthquake, continued from page 10)

Probably this is the arrival of the *P*(rimary)-wave from the earthquake. (The official timing for the earthquake at the epicentre was 07:07:49 HST, commensurate with our timing and the distance between the epicentre and Mauna Kea.) This is a longitudinal wave — causing compression and expansion of the medium (the ground) in the same direction as the wave propagation, much as with sound waves in air. About four seconds later, at about 07:07:58.5, according to our data, a much more violent event occurs — probably the arrival of the transverse *S*(econdary)-wave. Speaking personally, I remember this one very well. This was not your run-of-the-mill magnitude 3 or 4 magma-motion-induced volcanic event that residents of Hawaii experience so regularly. This was seismic, in all senses of the word. It was eventually registered as being of magnitude 6.7. Almost immediately the telescope servo loses the battle to keep the antenna pointed where it ought to be according to the inclinometry script. Inclinometry data is faithfully recorded (Figure 2) and after the violence of the *S*-wave has passed, it even looks like two of the meters have settled down. But the TY trace, from the tilt meter in the receiver cabin, does not return to base. A few minutes later a mag 6.0 after-shock is recorded by the remaining tilt meters, but the servo has long since lost the battle to keep the antenna where it should be. Rotation of the antenna appears to cease following the after-shock. Thirty minutes later the power goes out at JCMT when the UPS runs out of backup power, and the inclinometry program ends.

Thorough checks by JAC staff over the following few days proved that the JCMT has escaped relatively undamaged by comparison with other telescopes on Mauna Kea. Needless to say, we had to repeat the inclinometry. Fortunately we have not had the opportunity since to repeat the experiment of using the JCMT as a giant seismograph.

RxW First Light at 345 GHz

Remo Tilanus (*JCMT Head of Operations*)

Early last year, the JCMT Board approved the conversion of the 460/490 GHz channel of Receiver W (RxW) to 345 GHz to create a dual-polarization capability for the eSMA. I am pleased to be able to report that this conversion was successful and that RxWB, as the 345 GHz "B-band" channel was officially named, attained first light on March 7, 2007. Figure 1 shows the very first detection with RxWB, a total intensity image of Venus at 345 GHz, in an undersampled raster map aimed at determining the instrumental pointing offsets. Figure 2 shows a (very) short observation of the CO J=3-2 line in CRL618 from later that evening with a partially tuned, non-optimized receiver.

RxW was developed at MRAO in Cambridge (UK) and delivered to the JCMT in the summer of 1998. The receiver had 2 detectors, 'mixers', in each frequency band, operating at orthogonal polarizations: two (built by MRAO) for observations at 460/490 GHz (around 650 μm wavelength), and two built by SRON (Groningen, The Netherlands) for 690 GHz (450μm). 'W' stands for the 'wideband' design. An an optical analysis by Richard Hills (MRAO) showed that the receiver would be able to accommodate the larger beam at 345 GHz (850 μm), although space would be tight. Figure 3 shows the optical layout of the original C-band and new B-band channel on the the mixer plates inside the dewar: instead of the second 'flat' and a lens, the beam is folded back onto a focusing mirror. The first 'flat' the incoming beam intersects is in fact a grid that allows one polarization to go through to the D-band mixer (not shown) and reflects the orthogonal polarization to the B-band mixer. The new RxW has two of these mixer plates with one B-band and one D-band mixer each. All mixers use DIMES (Delft, The Netherlands) junctions.

In fact, obtaining two new B-band mixer blocks was the most critical issue standing in the way of a conversion. Fortunately, the MRAO group, under the management of Jane Buckle, was able to manufacture two HARP-style blocks on short notice and adapt them for use in RxW. Leo de Jong of SRON took advantage of the opportunity to outfit the D-band mixers with improved junctions that are hoped to significantly improve the performance of the receiver at that frequency. A new 'Zimmermann' Gunn oscillator assembly was purchased from RPG-Radiometer Physics in Germany. A host of IF components were ordered to allow a conversion of the IF from 4 GHz to the eSMA standard of 5 GHz. For one microwave LO component, a WR08 (107–120 GHz) ferrite modulator for use in the Gunn oscillator, no supplier could be found. Instead, a solid-state pin-diode attenuator was used, but if you happen to have a compatible modulator gathering dust on a shelf, feel free to drop us a note!

The actual conversion and reintegra-

(RxWB, continued on page 13)

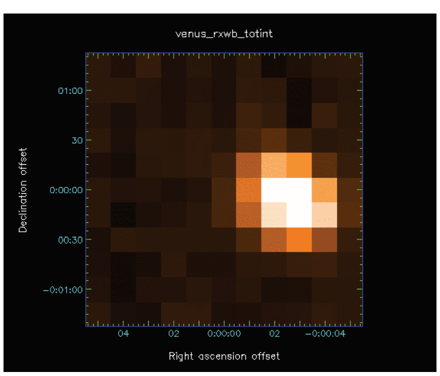


Figure 1. — Venus found!

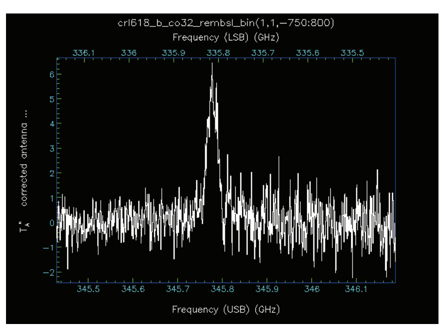


Figure 2. — CO J=3-2 emission line in CRL 618.

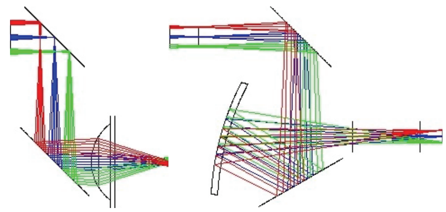


Figure 3. — Optical layout. (left) Original C-band design. (right) New B-band design.

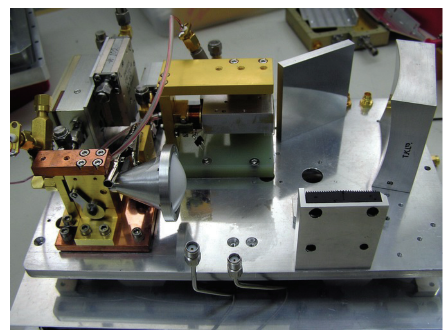


Figure 4. — One of RxW's mixer plate part-way assembled. The upgraded D-band mixer is in the front with a white lens and the new B-band mixer facing the curved mirror is behind it.

Figure 5. — Ken Brown 'enjoying' several weeks of use of a stereo microscope to solder wires and connectors for installation inside the cryostat.

Whither the Weather?

Gerald Schieven (*JCMT Support Scientist*)

Farmers and astronomers are more at the mercy of the weather than probably any other sector of society. The summit of Mauna Kea benefits from having its very own weather forecast (http://mkwc.ifa.hawaii.edu/forecast/mko/), provided twice daily by the Mauna Kea Weather Center (MKWC), administered by the UH Institute for Astronomy in cooperation with the UH Department of Meteorology. This forecast, along with a plethora of other information, is compiled on the JAC Weather page at http://www.jach.hawaii.edu/weather/ . There is an excellent summary of the mission and operations of the MKWC, in the Autumn 2006 *UKIRT Newsletter* (available at http://www.jach.hawaii.edu/UKIRT/publications/Newsletter/issue19/special.html).

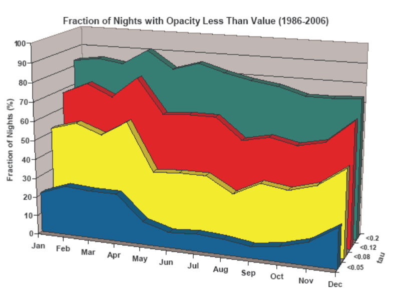


Figure 1. — Fraction of nights (% of total) over the period 1986–2006, where the τ_{225GHz} was equal to or less than the value specified, as a function of the month.

All of these facilities are extremely useful in determining the weather and atmospheric conditions now or over the next few days, but what if one needs an estimate of the probability of excellent/good/poor weather several months hence? For at least one aspect of the atmosphere of great concern to submillimetre observers, *i.e.*, the atmospheric opacity, we can check the average conditions over the past several years. Since 1989, the CSO tau-meter has been collecting opacity data at 225GHz. Originally built by NRAO, the instrument has long been operated and maintained by the Caltech Submm Observatory.

In Figure 1, we display the relative number of nights (as a percent fraction of the total number) that the atmospheric opacity at 225 GHz (τ_{225GHz}) is at or below a certain value, for each month of the year during the night. These values are the divisions between the weather bands used by the JCMT, *i.e.*, τ_{225GHz}<0.05 is grade 1 (*i.e.*, extremely dry) weather, 0.05< τ_{225GHz}<0.08 is grade 2 (dry), 0.08< τ_{225GHz}<0.12 is grade 3 (medium), 0.12<τ_{225GHz}<0.2 is grade 4 (wet), and τ_{225GHz}>0.2 is grade 5 (extremely wet). Figure 2 shows the same, but including only the most recent six years. It's immediately apparent, as any frequent user would know, that the summer is considerably wetter than the winter. However, the faction of extremely wet (τ_{225GHz}>0.2) weather does not change appreciably through the year. It's also quite apparent that the period 2000–2006 has a much smaller faction of time during the summer with extremely dry (τ_{225GHz}<0.05) weather compared to the average over 1989–2006.

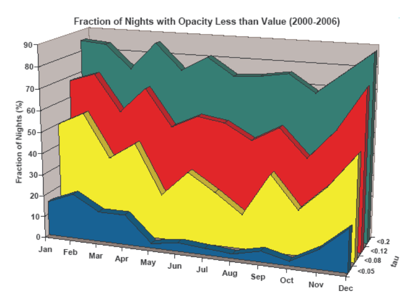


Figure 2. — Same as Figure 1, except just over the period 2000–2006.

Using these figures, one can estimate the fraction of time in July, for example, that the JCMT Legacy Surveys (JLS) will be able to acquire data (i.e. that the weather will be grade 2, 3, or 4). From figure 2, about 73% of the time is grade 4 or better, while only about 3% of the time is grade 1. Thus about 70% of the JLS time in July should be useful to them, on average.

(RxWB, continued from page 12)

tion of the receiver was carried out over a 5-month period at the JAC primarily by Ken Brown and Tim Chuter. This included a complete, but necessary overhaul of the wiring inside the cryostat that had developed faults in the course of operating the receiver. Figure 4 shows one of the mixer plates in the process of being assembled, but with the optics, both mixers and cold IF components already in place. The reassembly of the cryostat was completed in January. After the receiver was successfully cooled to operating temperatures, it was quickly established that all four mixers were healthy and operational. Unfortunately, during this work it was found that the original D-band Gunn assembly, which has been reported difficult to tune by the operators, had developed a fault and needed to be sent back to the manufacturer for repairs. Consequently we were unable to characterize the performance of the upgraded D-band mixers. RxW was remounted in JCMT receiver cabin with the new B-band channel available for observation. Preliminary tests indicate that the performance of the receiver at B-band is comparable to that of HARP. RxWB's 'single-pixel' dual-sideband and dual-polarization capability complements HARP wide-field mapping capability at 345 GHz at the JCMT.

A large part of the conversion effort of RxW was financially supported by a Netherlands' NWO-M grant awarded to Ewine van Dishoeck (Leiden University) in support of eSMA development. The grant provided for the technical expertise and support from Leo de Jong (SRON) and Rob Millenaar (ASTRON), who both came to the JAC for extended visits to assist with the conversion and commissioning of RxWB.

AzTEC: Visiting Millimeter-Wave Camera Explores the Cosmos

Jason Austermann (*Massachusetts*) & The AzTEC Instrument Team

AzTEC at the JCMT

AzTEC was built to be a first generation facility instrument of the Large Millimeter Telescope (LMT), a new observatory currently under development in Mexico as a partnership between the University of Massachusetts and INAOE (Instituto Nacional de Astrofisica Optica y Electronica) of Mexico. Since AzTEC was finished well ahead of the LMT schedule, AzTEC partnered with the JCMT for a commissioning/engineering run in June 2005. After successful integration and commissioning, AzTEC was brought back to the JCMT for a 2+ month scientific run in the winter of 2005/06 (see Figure 1).

AzTEC is a large-format bolometer array camera with a detector array comprising 144 silicon nitride micromesh bolometers. The AzTEC bandpass is defined through a series of changeable filters and coupling optics, although AzTEC worked exclusively at 1.1 millimeters during its time at the JCMT. AzTEC spent about 600 hours on-sky at the JCMT, undertaking a wide variety of projects including studies of the Sub-Millimeter Galaxies, star-forming regions, brown dwarfs, clusters, and the mapping of dust in nearby galaxies. Analyses of these data sets are ongoing (for example, see the GOODS-N article in this *Newsletter*).

AzTEC provided excellent performance throughout the JCMT run, with a median raw per-pixel sensitivity to *point-like* sources of 10.2 mJy $s^{1/2}$. Figure 2 shows some of the achieved raster mapping speeds for point-source maps given different weather conditions (opacities) and mapping strategies. These "empirical" mapping speeds factor in all overheads and inefficiencies of the observations, including time lost to telescope turnarounds when scanning.

Ground-based multi-pixel bolometer cameras have helped make significant advances in many areas of (sub) millimeter astronomy, with one of the most striking being the discovery of a population of high-redshift, FIR ultra-luminous starburst galaxies (Smail *et al.* 1997, Hughes *et al.* 1998). Now commonly referred to as Sub-Millimeter Galaxies (SMGs) or sometimes SCUBA galaxies, these objects were initially discovered using the highly successful SCUBA camera (Holland *et al.* 1999) on the JCMT. In the years following their discovery, SCUBA undertook many blank field surveys to characterize the SMG population (*e.g.*, Coppin *et al.* 2006, Scott *et al.* 2006 and references therein). Recently, other large-format (sub-)millimeter continuum cameras have come online and performed SMG surveys (*e.g.*, Laurent *et al.* 2005, Greve *et al.* 2004), including the 144 pixel BOLOCAM (Glenn *et al.* 2003) operating at 1.1mm on the Caltech Submillimeter Observatory (CSO) and the 37/117 pixel MAMBO/MAMBO-2 cameras (Kreysa *et al.* 1998) operating at 1.2 mm at the IRAM 30-m telescope.

Why are SMGs so important? These presumably massive galaxies are found primarily at high redshift and provide a unique tracer to structure formation and evolution. The distribution of SMGs in redshift and how

(AzTEC, continued on page 15)

Figure 1. — Installation and optical alignment of AzTEC in the JCMT receiver cabin.

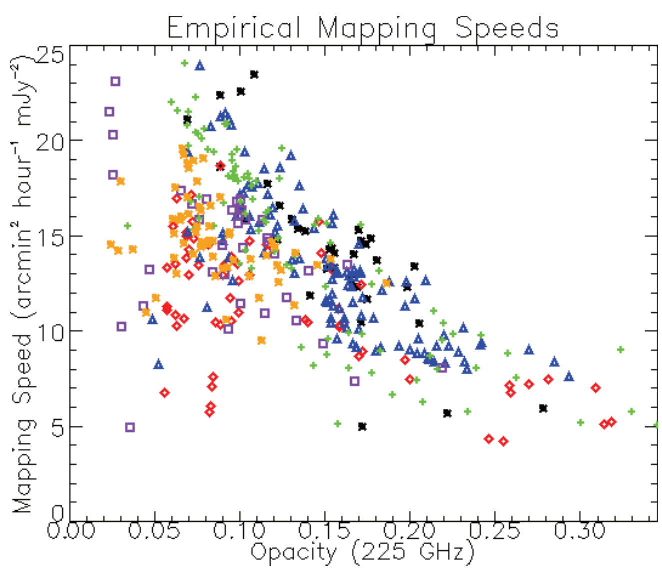


Figure 2. — Empirical raster point-source mapping speeds for the AzTEC/JCMT system during various atmospheric conditions. Opacity measurements are from the CSO tau meter. Mapping speed estimates include mapping inefficiencies such as time lost to telescope turnarounds (can be upwards of 50%), such that this metric should represent effective (actual) performance. Colors/shapes represent different observing strategies (e.g., map sizes, scanning speed), showing that effective mapping speed is a function of both weather and strategy. Data reduced using the current (Feb 2007) versions of the AzTEC data reduction software package.

The Last Word

Gerald Schieven (*Editor, JCMT Support Scientist*)

It is indeed a great thrill for an editor to see the results of one's labour appear in print, especially when the last time it did appear in print was nearly eleven years before. September 1996 was the last time *Spectrum* (them simply called the *JCMT Newsletter*) appeared as a glossy publication; since that time it was only available on-line. The featured article of that issue was, "SCUBA is now on the JCMT!!!", printed in large, friendly letters on the cover. Since that time, SCUBA was commissioned, started operations, became one of the highest-scientific-impact astronomical instruments (see the September 2001 *JCMT Newsletter*), and finally after a decade on the telescope, was retired due to "illness" while still the highest-demanded instrument on the telescope. By the next *Newsletter*, we should have a similarly entitled lead article, substituting SCUBA-2 for SCUBA!

This is my eleventh issue as editor, since March 2000 (with a brief hiatus in 2004 and 2005). Starting with the spring 2006 issue, the *Newsletter* has had two editors. My co-editor, Jonathan Kemp, is the person to credit for the layout and appearance of this publication. All I've had to do is to solicit (*i.e.*, arm-twist) articles and images, and the odd fiddle with the text to make things fit. Many thanks to Jonathan.

(AzTEC, continued from page 14)

early they formed can provide important constraints and challenges to current structure formation models. The intense levels of FIR radiation from these objects imply that they are undergoing extreme levels of dust-enshrouded star-formation (~10^3 $M_\odot$ yr^{-1}; Blain *et al.* 2002), thus potentially providing a measurement of the star formation history of the universe over a range of redshifts. The expected emissivity index of the dust causes these galaxies to have a strong negative *k*-correction at millimeter wavelengths that roughly compensates for cosmological dimming; thus, any SMG of a given luminosity is (approximately) equally detectable between redshifts of 1 to 10 and blind surveys are effectively volume unlimited. These hyper-luminous star forming galaxies are not seen in the local universe, which begs important questions: What modern day objects are the products/remnants of SMG's? Is their star formation episodic or relatively continuous? How are these massive galaxies associated with modern day clusters and cluster formation? How compact are these sources and could they be multiple (possibly merging) galaxies?

During its time at the JCMT, AzTEC undertook several independent projects to survey the SMG population over large portions of the sky. These projects include 'blank-field' surveys of the full 0.5 deg^2 of the original SHADES fields (PI: James Dunlop), a 0.2 deg^2 portion of the COSMOS field (PI: David Sanders), and the entire GOODS-N field (PI: Edward Chapin). AzTEC also conducted two large surveys around regions of mass bias: 4C 41.17 (PI: David Hughes) and MS0451 (PI: Ian Smail). (SHADES covers ~0.25 deg^2 of the Lockman Hole and SXDF fields, each. The SHADES surveys were initially conducted using SCUBA; however, SCUBA's untimely demise left these surveys incomplete. AzTEC has observed the full 0.5 deg^2, including the parts mapped by SCUBA, thus providing interesting multi-frequency (450, 850 and 1100 μm) coverage over portions of these fields.)

While relatively small surveys of the past have done well to characterize the faint and intermediate number counts, these large AzTEC surveys provide the best probe of the bright (and rare) end of the SMG population. The AzTEC surveys should also overcome some of the biases incurred by smaller surveys due to clustering and cosmic variance.

Nearly 2/3 of AzTEC's telescope time at the JCMT was spent on SMG related projects, resulting in over 1 deg^2 of sky being mapped to 1σ depths of 0.8–1.4 mJy. When taken alone, these AzTEC surveys will go a long way in advancing our statistical knowledge of SMG number counts, SMG clustering, and cosmic variance. Overall, these surveys have detected a few hundred SMG candidates, most of which were previously unknown/undetected. When coupled with multi-wavelength and redshift data, these AzTEC catalogs should provide insight into large-scale structure, cluster and galaxy formation and evolution, star formation history, and the nature of SMGs themselves.

More information on AzTEC is available at the AzTEC Instrument home page: `http://www.astro.umass.edu/AzTEC/`.

References

Blain, A.W., *et al.* 2002, *Phys. Rep.*, 369, 111

Coppin, K., *et al.* 2006, *MNRAS*, 372, 1621

Glenn, J., *et al.* 2003, *Proc. SPIE*, 4855, 30

Greve, T.R., *et al.* 2004, *MNRAS*, 354, 779

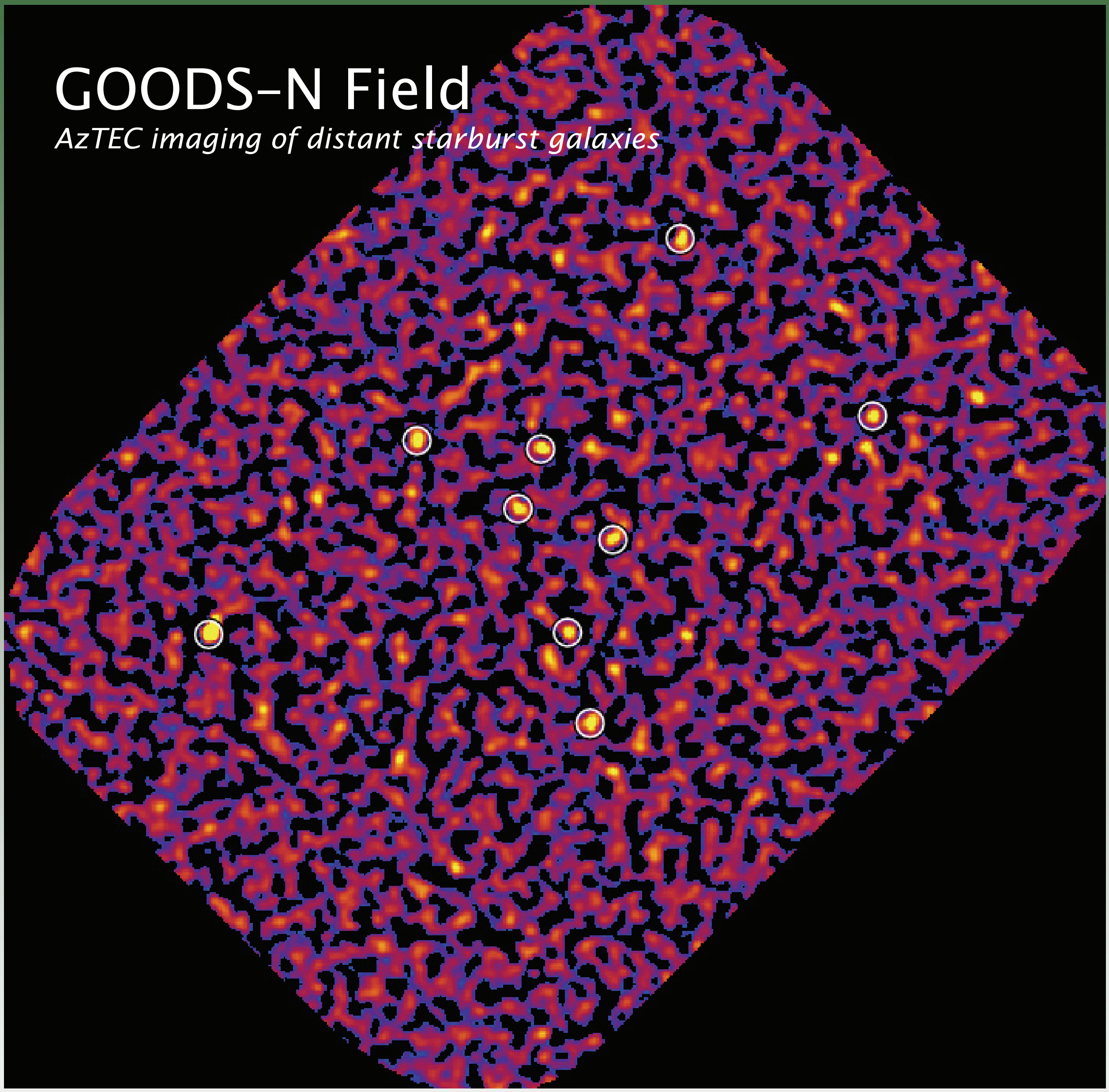
Holland, W.S., *et al.* 1999, *MNRAS*, 303, 659

Hughes, D.H., *et al.* 1998, *Nat*, 394, 241

Kreysa, E., *et al.* 1998, *Proc. SPIE*, 3357, 319

Laurent, G., *et al.* 2005, *ApJ*, 623, 742

Scott S.E., Dunlop J.S., & Serjeant S., 2006, MNRAS, 370, 1057



www.jach.hawaii.edu/JCMT

jk