JCMT NEWSLETTER

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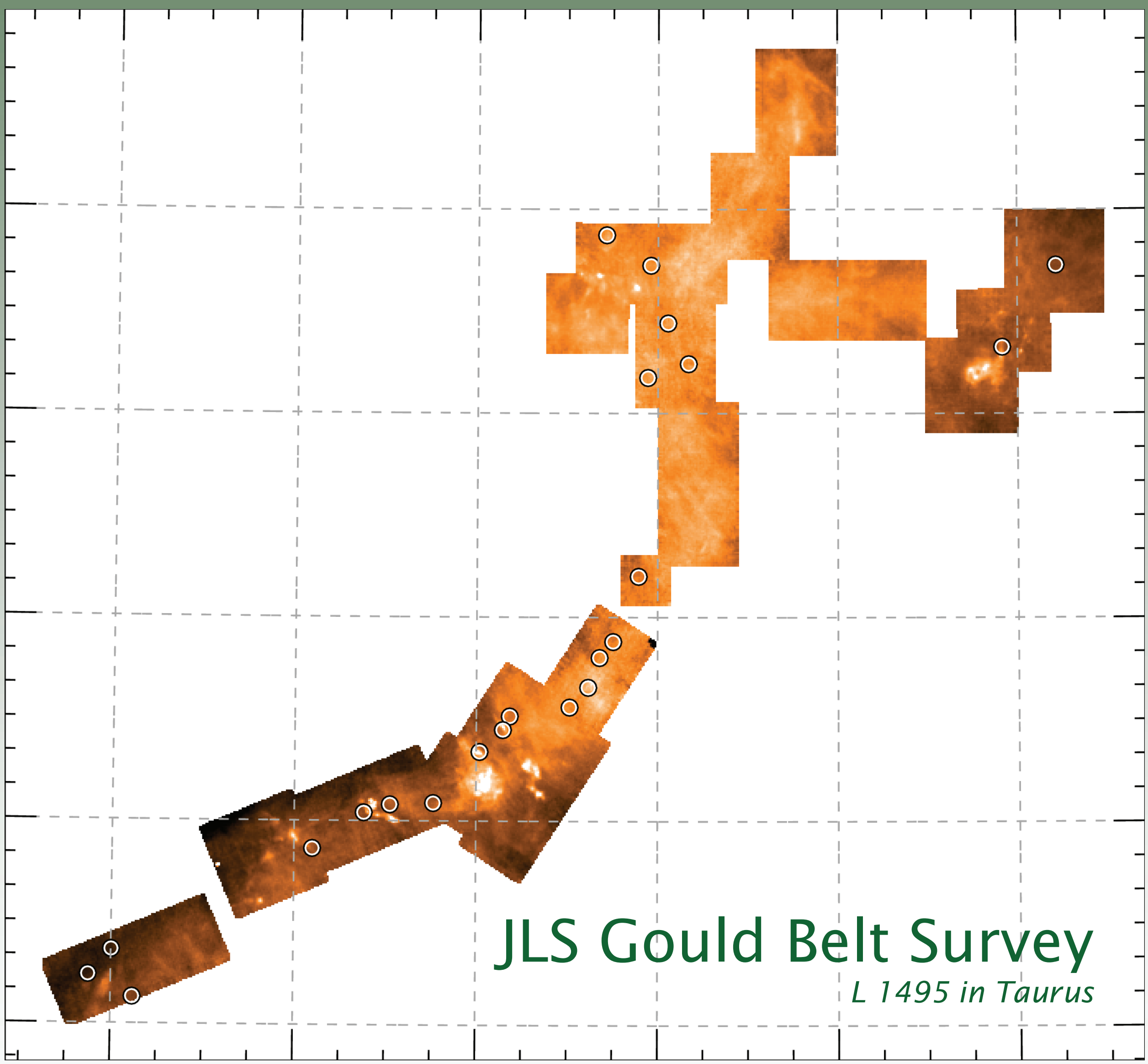


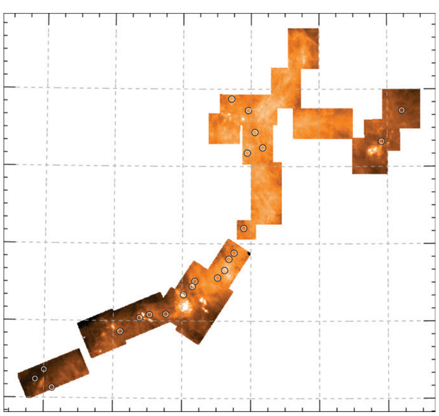
JLS Gould Belt Survey

L 1495 in Taurus

JLS Survey Updates

SCUBA-2 Status Update

In This Issue



On the front cover: GBS HARP/ACSIS ^{12}CO integrated intensity map of Taurus L 1495, with $H^{13}CO^{+}$ cores (Onishi et al. 2002) marked. (Also see Figure 1 on page 7 and article on page 6.)

On the rear cover: Celebrating the International Year of Astronomy, Hawaiian style. Featured JAC staff include Inge Heyer (upper right, middle right), Frossie Economou (lower left), and Remo Tilanus (middle left). Also, JAC student intern Kyle Cannoles (center). (Also see article on page 15; images courtesy Inge Heyer/ JAC.)

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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 2009 edition of the JCMT Newsletter. This issue is dedicated to the JCMT Legacy Survey (JLS), which at the time of writing this column has been running for 16 months. Each of the three teams with HARP/ACSIS components to their surveys — the Gould Belt Survey, the Spectral Legacy Survey and the Nearby Galaxies Survey — were invited to provide an article giving some of the scientific highlights that have emerged from their observations. The results are exciting and promising, showing just a fraction of what the surveys will finally offer.

The most important JLS-related business to occur in the last 6 months has been the review which took place last Winter. Since before the JLS began taking science data in November 2007, it has been known that the observing efficiency of HARP/ACSIS on the telescope was not as anticipated at the time the proposals were written. After ten months of survey operations the JCMT Board called for a review of progress to be carried out by the JCMT Surveys Oversight Committee (JSOC). Each of the three teams involved in the review provided a detailed report on survey management, data reduction and quality assurance handling, and a justification for an extended allocation to complete their survey. After reviewing the documents, the JSOC made their recommendation to the Board which was subsequently approved. The result is an extra 499 hours of observing time for the three teams to complete the HARP/ACSIS components of the JLS, as well as an adjustment of the allocated weather bands to improve data quality and the chances of success. This is a great result and shows the commitment of all involved to the survey programme.

The majority of the time allocated to the JLS is for observations with SCUBA-2. As we write this column, auditors from the UK are visiting the JAC on their regular three-year cycle, and one of the topics we will be discussing with them is best practice for carrying out an *ex post facto* review of the project. This is in fact a very welcome and positive sign, since it demonstrates that we are building up to the conclusion of the project. The current situation is that the instrument has been commissioned in its as-delivered state: it has been installed and aligned on the telescope, the control and data acquisition software have been integrated into the observatory environment, and the observing modes and data reduction pipeline have all been tested and work well. As is only to be expected with an instrument of this complexity, some unexpected problems were encountered during the commissioning, but solutions are in hand for all of these and there are no technical show-stoppers. The biggest surprise was the sensitivity of the detectors to the local magnetic field: the SQUID readout devices are very sensitive magnetometers and although the instrument was designed with careful attention to magnetic shielding, this was found to be inadequate in the telescope environment. A combination hardware/software solution has been developed and we expect this to be fully under control in the next cooldown.

The instrument was delivered with two engineering-grade arrays which, although adequate for commissioning the instrument as described above, do not meet the science-grade specification. Given the excellent progress described above, we are well-positioned to move rapidly into on-sky commissioning once the science-grade arrays arrive in Hawaii. The current schedule has the first two science-grade arrays arriving in June, with the remaining six arriving in October. There is therefore a realistic prospect of commencing astronomical observations with this long-awaited and much-anticipated instrument by the end of 2009. We will certainly keep the community informed of developments.

Antonio Chrysostomou, Associate Director JCMT

Work to fully commission the eSMA, our programme of collaborative submillimetre interferometry with the CSO and SMA, is ongoing. Dedication ceremonies were held in November, and were attended by Dr. Louis Vertegaal and Dr. Ronald Stark of our Netherlands funding agency, NWO. The event was filmed for Dutch television. At the time of writing this column we have just completed a long run of science demonstration observations in the 345-GHz band using RxWB, and pending the outcome of the data analysis we hope to shortly be in a position to issue a Call for Proposals for this unique system.

It is interesting to note that when one looks at the JCMT's instrument complement in 2005, every instrument has been either replaced or upgraded in the past four years with one exception: RxA3. This venerable receiver has served the community well over the past decade, but it is no longer state-of-the-art and it is increasingly difficult to support given its aging components (including 5.25-inch, single-sided,

(Director's Desk, continued on page 4)

The JCMT Legacy Survey: The First 16 Months

Antonio Chrysostomou (*Associate Director JCMT*)

The JCMT Legacy Survey (JLS) is an ambitious project to make the first unbiased survey of the sky in the submillimetre. Inspired by the promise of new instrumentation on the JCMT (SCUBA-2 and HARP/ACSIS), the project will enable large regions of the sky to be efficiently and sensitively mapped. In the Winter of 2005 a two-day meeting was convened in Leiden, attended by the majority of the JCMT community from across the three partner countries. At this meeting, the community came together to fashion the seven projects which now make up the JLS. To ensure currency, validity and importance all proposals were peer-reviewed by an international list of referees and assessed by the JCMT Surveys Steering Group (JSSG). Following final recommendations from the JSSG, the JCMT Board endorsed the JLS in the summer of 2005, giving the project 55% of all the time available to the partner countries to complete (Table 1 shows the actual allocations awarded).

In November 2007, following a phase of science verification, the JLS began taking its first survey data for those projects containing HARP/ACSIS as a component: the Gould Belt Survey (GBS), the Spectral Legacy Survey (SLS) and the Nearby Galaxies Survey (NGS). Progress on these surveys can be followed on the JLS web site (`http://www.jach.hawaii.edu/JCMT/surveys/`). In this special edition of the JCMT Newsletter, each of these teams has

(JCMT Legacy Survey, continued on page 5)

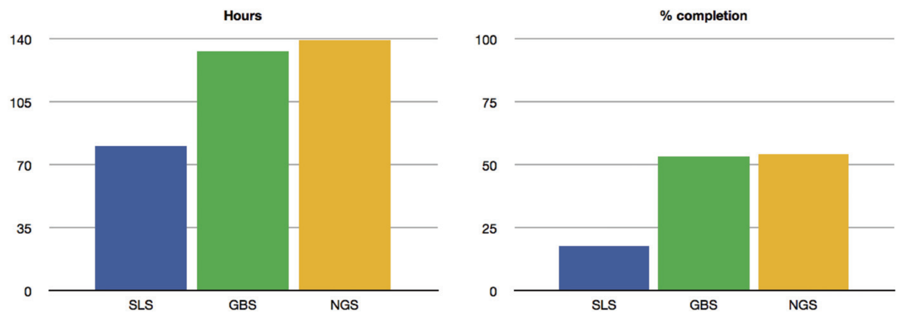

Figure 1. — Survey progress since the JLS began in November 2007. The panel on the left shows the number of hours that have been charged to the teams, and the panel on the right shows the fraction of the total allocation used (following the JLS Review 2008).

(Director's Desk, continued from page 3)

low-density floppy disks!). In 2008, an ad hoc panel was commissioned to review the scientific case for maintaining an A-band capability at the JCMT. We are grateful to Mark Thompson, Rene Plume and Michiel Hogerheijde for carrying out this review. The panel's report strongly promoted the continued commitment of the observatory to this frequency band, and on this basis (as well as for operational reasons) we are currently considering options for upgrading or replacing this receiver. It should be noted, though, that until the Board approves an upgrade project and resources for the work are identified, the default position is that RxA3 will remain our operational A-band receiver for the foreseeable future.

A survey of the Starlink Software Collection was recently conducted asking for users' views on the software suite that is now solely supported and developed by the JAC. The reason for the survey is that at the same time as the Starlink software is being actively developed, we are seeing a proliferation of operating systems (and their various flavours) amongst our user base. Providing and supporting the software on these various platforms is becoming increasingly difficult and time consuming and so it was decided to poll the community to obtain a snapshot of the computing facilities available to them and to gauge just how pervasive the problem of supporting Starlink software on multiple platforms is. Although the results of the survey have yet to be analysed the response was exceptional, with over 200 responses received, for which we are thankful to the JAC community, and shows that it is still very much involved and committed to the Starlink Software Collection.

2009 is the International Year of Astronomy, and the JAC is taking part in celebrations in a variety of ways. This included a live web-cast from the control room of the JCMT which was broadcast on April 3rd 10:20 UT, a 15-minute cameo in a 24-hour segment called *Around the World in 80 Telescopes* which in turn forms part of the *100 Hours of Astronomy* event. More details on other IYA 2009 activities can be found in the article by Inge Heyer, the JAC Outreach Officer, in this Newsletter.

Finally, we have only one staffing change to report on this occasion. After many years with the Starlink project as scientific programmers, David Berry and Peter Draper have been effectively working for the JAC since the Starlink project was terminated in 2005. This arrangement (resourced by our UK funding agency STFC, for which we are grateful) has enabled the continued development of the Starlink software collection to accommodate the requirements of the JCMT's new instrumentation suite. This development is now essentially complete and David has joined the JAC Software Division as a Starlink programmer to provide ongoing maintenance of the collection.

(JCMT Legacy Survey, continued from page 4)

contributed a science article giving highlights from the first 16 months of observations. There have been problems and issues to overcome in this time, both major and minor, but the results that are coming through are exciting and at times breathtaking.

JLS Progress

The three articles in this edition of the Newsletter give a concise overview of the progress made thus far since the JLS began in earnest 16 months ago.

The GBS will utilise three instruments (HARP/ACSIS, SCUBA-2 and POL-2) to achieve its goal of better understanding low-mass star formation by studying the nearby molecular clouds which make up the Gould Belt. The key goals for the survey are given in the article. HARP/ACSIS is utilised primarily to better understand the gas kinematics in these clouds in order that the role of outflow, infall and turbulence can be placed in context in driving and regulating star formation. Already four major star forming clouds have been mapped in the main ^{12}CO J=3-2 transition and the results from Serpens (in one of the most visually stunning images from the JLS thus far) clearly demonstrates the importance that feedback must play in star formation.

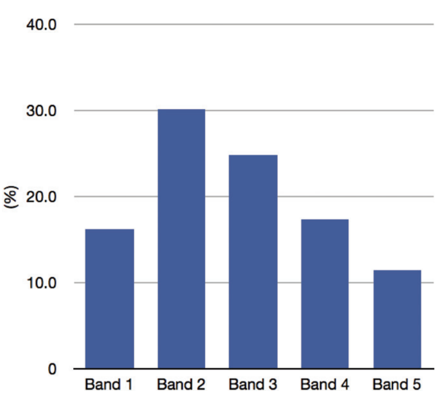

Figure 2. — Distribution (%) of weather during all JLS observing blocks since the survey began in November 2007. Note that the majority of the weather fell in band 2 and band 3 allowing the GBS and NGS teams to take the most advantage.

The SLS will be a survey to go deeper (or as deep) than any other current or previous submillimetre spectral survey. In a different approach to any of the other surveys in the JLS, the SLS is purposely biased in its choice of sources (of which there are four) but unbiased in the spectral range covered (curtailed only by the constraints of the atmospheric window and the survey's weather allocation). The aim is to map four disparate Galactic star forming regions completely between 330 and 362 GHz. To extend the survey, the team have obtained time allocated in better weather conditions from the national TAGs to secure data at the edges of the passband. They have also extended their survey to lower frequency using the RxA instrument. The overall aims are to obtain a chemical census in a diverse range of star forming environments and interesting results are already coming through in the data presented in this Newsletter and in the latest papers. The work investigating whether the HCO^+ and HCN tracers can reliably follow star formation activity demonstrates the wide-ranging potential that detailed and careful spectral studies can provide.

The NGS will ultimately obtain ^{12}CO J=3-2 data on 155 galaxies that lie within 25 Mpc from our Galaxy, spanning all ranges of morphological type. The data are providing a wealth of information to the NGS team as can be seen from their article. The gas depletion timescales of spiral galaxies in the Virgo Cluster has been measured, differences in properties such as star formation efficiency are found between galaxies in the Cluster, and for some galaxies no correlation is found between star formation efficiency and the surface density of the molecular gas. Intriguingly, NGC 628, a galaxy seen almost face on, has been discovered to have a low velocity dispersion, implying a very small scale height for the molecular gas.

Quality Assurance and the ORAC-DR Pipeline

The ORAC-DR pipeline is integral to observatory and JLS operations and its development continues. The pipeline is run at the summit and used by our observers to gauge how well the observing is proceeding. The most recent releases of the pipeline include new "advanced" processing recipes (which are not run at the telescope due to the length of time it takes to process data in this mode). These recipes produce improved data products over the normal pipeline using an iterative approach to removing spectral baselines. Instructions on how to download the pipeline software and keep up to date with patches

(JCMT Legacy Survey, continued on page 6)

Table 1.
Allocations to the JLS by the Board, including recent revisions following a review of progress in late 2008.
A full breakdown (by weather band and instrument) can be found in http://www.jach.hawaii.edu/JCMT/surveys/SurveyAllocations.html .

Survey	Total hours awarded originally	Total hours awarded following the JLS Review 2008
SCUBA-2 "All-Sky" Survey (SASSy)	500 (15.7 %)	500 (13.6 %)
Cosmology Legacy Survey (CLS)	1120 (35.1 %)	1120 (30.4 %)
Nearby Galaxies Survey (NGS)	205 (6.4 %)	331 (9.0 %)
JCMT Plane Survey (JPS)	334 (10.4 %)	334 (9.1 %)
Gould Belt Survey (GBS)	508 (16.0 %)	612 (16.6 %)
Spectral Legacy Survey (SLS)	187 (6.0 %)	456 (12.4 %)
Debris Disk Survey (DDS)	330 (10.4 %)	330 (9.0 %)
Total	3184 (265 nights)	3683 (307 nights)

The JCMT Gould Belt Survey (GBS)

Jennifer Hatchell (*Exeter*), Jane Buckle (*Cambridge*), Glenn White (*Open*), John Richer (*Cambridge*), Chris Davis (*JAC*), & The JLS GBS Consortium

The JCMT Gould Belt Survey (GBS) targets the regions of star formation closest to the Sun, which are associated with the Gould Belt — a ring of nearby O-type stars inclined at about 20 degrees to the Galactic Plane, centred on a point roughly 200 pc from the Sun and about 350 pc in radius. The Gould Belt contains almost all of the well known low-mass and intermediate-mass star-forming regions within 0.5 kpc, and a main motivation for our survey is to map these regions with SCUBA-2 in the dust continuum. Of course, SCUBA obtained fantastic data on star forming regions (*e.g.*, di Francesco et al. 2008), but maps were limited to a few square degrees of the densest molecular cloud regions and we still have a very incomplete picture of the distribution of dense, star-forming cores. The fast mapping speed of SCUBA-2 means we should be able to map hundreds of square degrees, sampling a much wider range of environments, all with better sensitivity than previously possible. However, SCUBA-2 is not the only new instrument on JCMT and the GBS is taking full advantage of the capabilities of the new spectral line receiver HARP and spectrometer ACSIS to obtain crucial velocity and density information. The GBS target clouds include favourites such as Perseus, Orion, Ophiuchus, Taurus and Serpens as well as lesser-known clouds: IC 5146, Scorpius, Pipe Nebula, Polaris Flare, Cepheus, Corona Australis, Lupus and small clouds. Full details can be found in the GBS PASP paper (Ward-Thompson et al. 2007).

(JLS GBS, continued on page 7)

Table 1.
Key goals of the Gould Belt Survey line observations.

• To search for and map any high velocity outflows present in cores, and thus differentiate between starless and protostellar cores; to derive simple constraints on the column density and CO depletion in these cores.
• To help understand the support mechanisms and core evolution.
• To characterize the cloud kinematics in a large sample of environments and investigate the evolution and role of turbulence in star formation.
• To test the relative importance of turbulent and magnetic support, when combined with POL-2 maps of their associated magnetic fields.

(JCMT Legacy Survey, continued from page 5)

and fixes can be found at `http://www.jach.hawaii.edu/JCMT/surveys/JLS_oracdr.html`.

The most recent development to the pipeline has been the inclusion of quality assurance (QA) that allows the pipeline to make real-time decisions on the quality of data. This is most useful at the telescope as following a calibration observation, the pipeline can inform the observer & TSS whether the present conditions and instrument performance are sufficient for any data observed to pass quality assurance for a particular survey. The JLS teams have been involved in the development of the QA pipeline. Most notably, the GBS team use the QA pipeline for all their quality control.

Progress to Date

Figure 1 shows how the JLS has progressed since it began in November 2007. At this point of the survey, the GBS and NGS have made good progress and are half way through their allocation. The SLS have some ground to make up, at least as a fraction of their allocation, and this is due to a number of factors but primarily because the weather has been better than anticipated during the nights that the JLS has been scheduled (Figure 2).

JLS Review 2008

Work done during science verification and once JLS observing had started indicated that the observing efficiency of HARP/ACSIS on the telescope was not as anticipated at the time the JLS proposals were prepared and submitted. The observatory implemented measures that did improve observing efficiency, but these were not sufficient to claw back the deficit. Given this, and that the JLS has to absorb calibration observations within its allocation, it became clear that the projects would not be able to complete in the time awarded. In response to this, the JCMT Board called for a review of the JLS to be undertaken by the JCMT Surveys Oversight Committee (JSOC).

Each team submitted a document reviewing their progress (data acquisition and reduction, QA, survey staffing and management, scientific exploitation) and provided justification of the time they would require to complete their surveys. The review concluded that the teams were committed to the success of the JLS and found this to be most encouraging but not surprising given their dedication.

In considering the cases for extending more time to the three JLS projects, the JSOC concluded that there was a strong case for additional time to be awarded and made that recommendation to the JCMT Board. At its meeting in December 2008, the Board approved a substantial total increase in allocation of 499 hr. A summary is given in Table 1 and more details are provided at `http://www.jach.hawaii.edu/JCMT/surveys/JLS2008.html`. It is the intent of the JCMT Board to have the HARP/ACSIS components of the JLS as complete as possible before SCUBA-2 becomes available for JLS science. With the HARP/ACSIS components of the project now more or less half way through, the results presented in this issue of the Newsletter provide just a small sampling of the science that will become available to our community in the coming months. Enjoy!

(JLS GBS, continued from page 6)

With HARP, we have begun taking data in three CO isotopologues: ^{12}CO, ^{13}CO and $C^{18}O$ J=3–2. HARP's 16-element array gives a more than tenfold increase in mapping speed over the old RxB and makes maps of sizes greater than 10'×10' feasible, even in the rarer isotopologues. The combination of dust continuum maps from SCUBA-2, magnetic field direction maps from POL-2, and line datacubes from HARP/ACSIS at matched resolution will be extremely powerful. Star formation involves many motions, including turbulence, infall, outflow and rotation. Tracing these motions is critical to understand the process of mass assembly, the role of feedback, and efficiencies in star-formation, and this can only be done through spectral line observations.

GBS HARP/ACSIS observations began in Summer 2007 with science verification observations of the main star-forming core in Serpens. Since then we have staffed JCMT with GBS observers for roughly 400 hr of observing and acquired 100 hr of data. Much of our time at the telescope is spent waiting for the very good weather ($0.05<\tau_{225}<0.065$) needed to observe the $C^{18}O$ line, which lies close to the water line at the edge of the spectral window. In contrast, ^{12}CO outflow mapping to 0.3 K on 1 km/s takes just a few hours, and can be done in mid-grade weather. So far, we have mapped the Serpens main core, Ori B (NGC 2024 and NGC 2071), Taurus L 1495 and Oph B. The 3–2 transition traces warm, dense gas with an excitation temperature of 30 K and a critical density of 104 cm^{-3}, quite different from the large scale CO 1–0 maps we are used to seeing from Bell Labs and FCRAO which highlight cold, diffuse gas. The three lines yield different information: ^{12}CO 3–2 is an ideal tracer of warm molecular outflows but rapidly becomes optically thick in the dense cores; $C^{18}O$ traces the dense clumps and the cores (though depletion can lower its abundance by a factor of 10 or more); and ^{13}CO, which is observed simultaneously and therefore 'for free' with $C^{18}O$, gives optical depth information and a good view of the lower-extinction parts of the cloud. For $C^{18}O$ the GBS has a stringent sensitivity requirement of 0.3 K RMS on 0.1 km/s resolution channels so that we can trace the velocity field in and around the cores.

Orion

NGC 2024, the Flame Nebula, a bright emission nebula crossed by a prominent dust lane, is one of the main star formation regions identified within the Ori B complex, the nearest high mass star forming region. Figure 2 shows the ^{12}CO integrated intensity contours overlaid on a DSS image (available through the Gaia image server).

The molecular gas associated with NGC 2024 shows complex emission line shapes, suggestive of a blister model surrounding an H II region (Barnes et al. 1989, Figure 10; Emprechtinger et al. 2009, Figure 1). In this model, the H II region heats surrounding material, leading to layers of foreground and background material at different velocities, temperatures and densities.

Position-velocity maps provide an excellent visualisation of the velocity structure. In Figure 3, the dense dust lane traced by $C^{18}O$ is in front of both the H II region and the dense molecular cloud, where the cuts in declination show outflows extending to high velocities. Emission at 3–5 km/s extends across much of the map, and was previously believed to be foreground material, but extensions from the emission of the main cloud towards the fragmentary features suggest that this material may be connected. In right ascension, the region traced by bright optical emission is clearly mapped by a

(JLS GBS, continued on page 8)

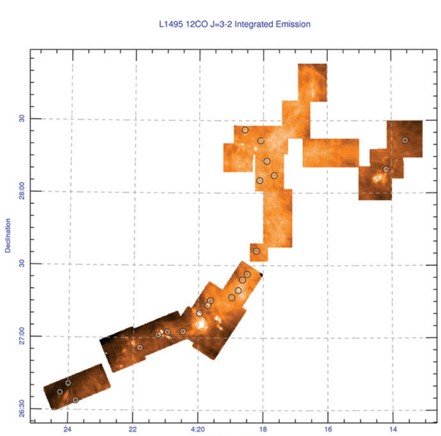

Figure 1. — GBS HARP/ACSIS ^{12}CO integrated intensity map of Taurus L 1495, with $H^{13}CO^{+}$ cores (Onishi et al. 2002) marked. (Also see front cover of this issue.)

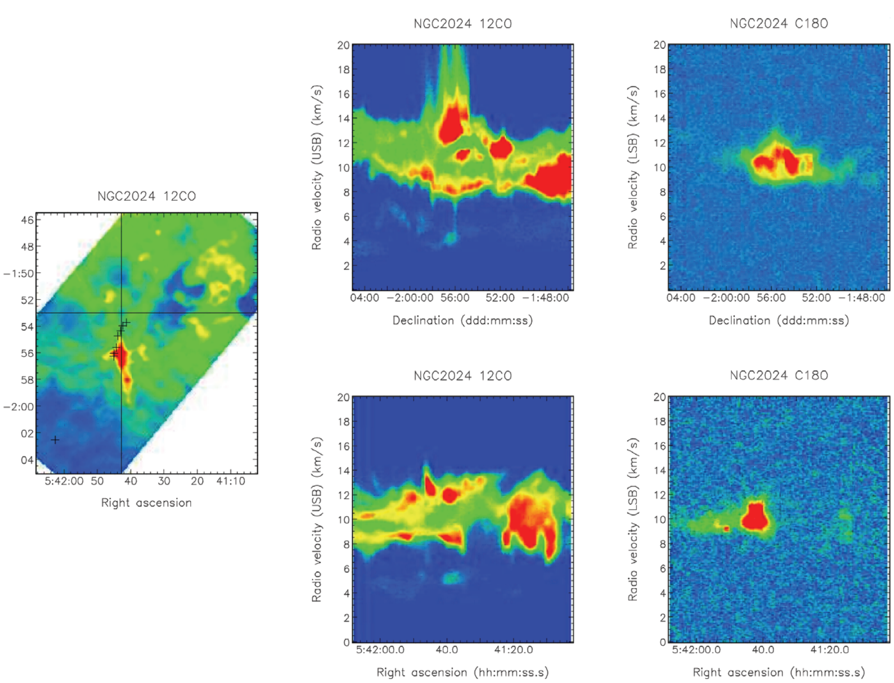

Figure 2. — (left panel) ^{12}CO integrated intensity map, with ^{12}CO and $C^{18}O$ position-velocity cuts along (upper-right panels) declination and (lower-right panels) right ascension as indicated.

(JLS GBS, continued from page 7)

'cavity' in ^{12}CO emission. At low velocities the emission shows a sharp cut-off; this may be where the H II region has broken through the bulk of the molecular gas.

Serpens

Our early maps of the main Serpens cloud core (Figure 4) illustrate spectacularly how young protostellar clusters drive outflows into their surrounding medium. This compact protocluster is known to contain several tens of deeply embedded, very young YSOs, and the HARP/ACSIS ^{12}CO images reveal the dramatic and explosive jets of gas, from multiple sources, which are currently depositing a significant amount of energy and momentum into the cloud. Even at this early stage of evolution the mechanical energy of the outflows represents a significant fraction of the cloud binding energy, which gives a direct indication of the importance of feedback processes in star cluster formation.

Taurus

The star formation in Taurus is quite different from the dense clusters of Serpens or Orion, with much more scattered and isolated cores. We have chosen to map L 1495 (Figure 1), an intriguing region in the north-west corner of Taurus for which there are relatively little data already in the literature. Our approach has been to map a large, fairly unexplored area, following low resolution extinction maps and a survey of molecular cores conducted by Onishi et al. (2002). We can make a census of outflow activity and star formation in L 1495 to compare with the other well-known star-forming regions (*e.g.*, Serpens, NGC 1333, Ophiuchus). Our next aim will be to examine the evolution of star formation throughout L 1495, comparing and contrasting the star formation rate along the south-east 'ridge' and across the north-west 'bowl', and relating this to the large-scale cloud structure and ambient magnetic field (note that recent stellar polarization measurements show that the

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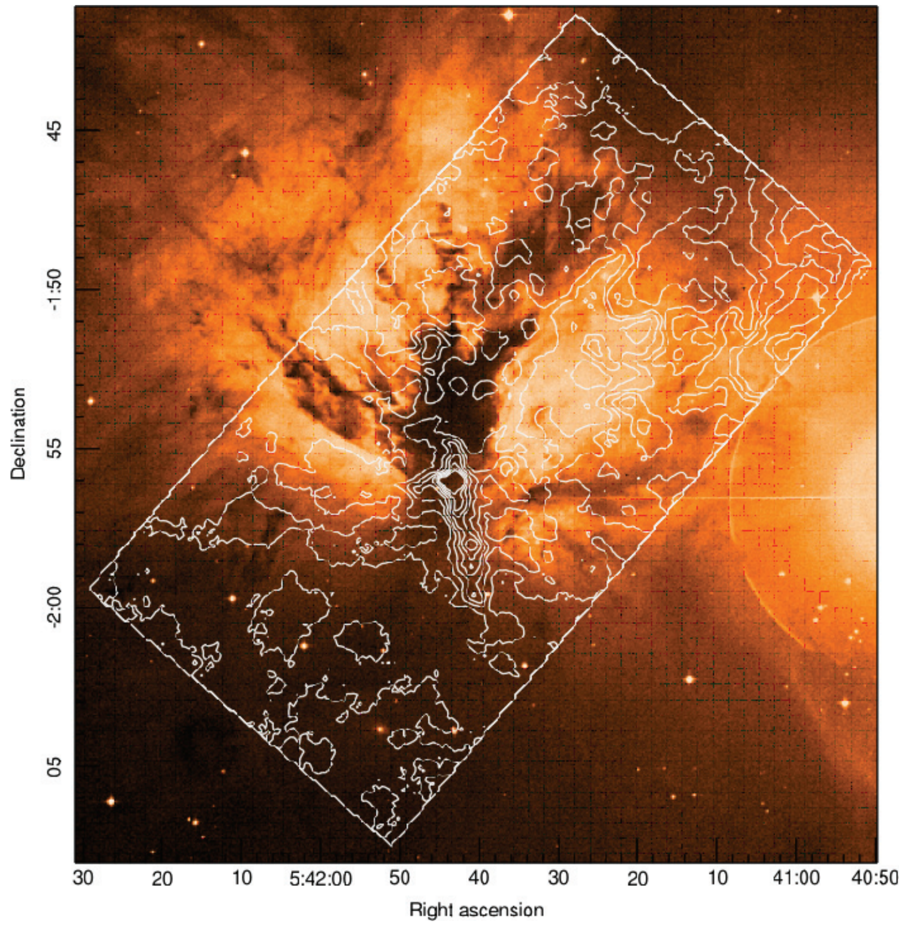

Figure 3. — ^{12}CO contours of NGC 2024 overlaid on a DSS optical image.

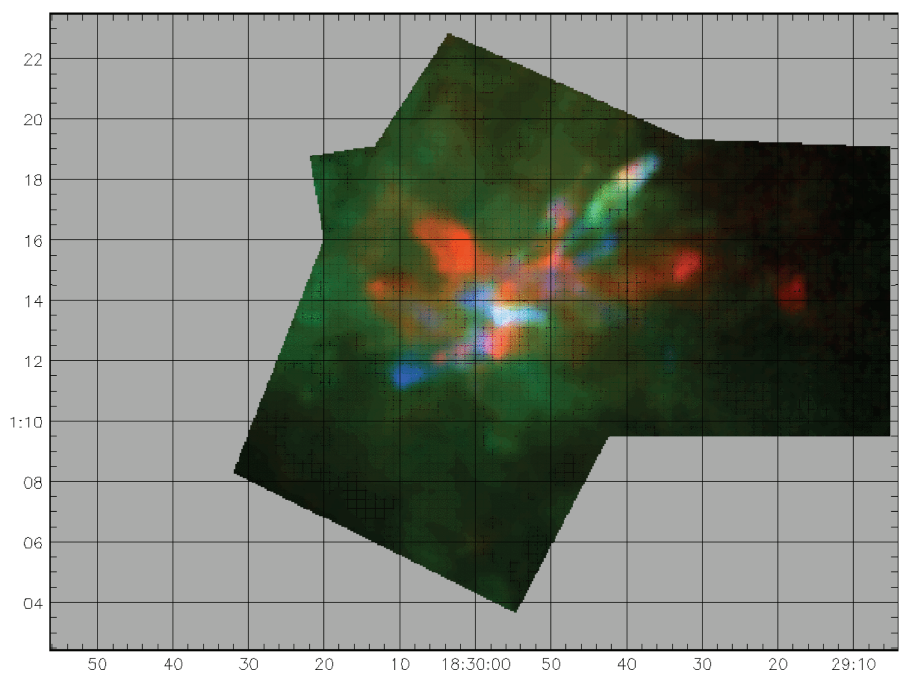

Figure 4. — A burst of redshifted and blueshifted outflows from the Serpens cloud core imaged in ^{12}CO.

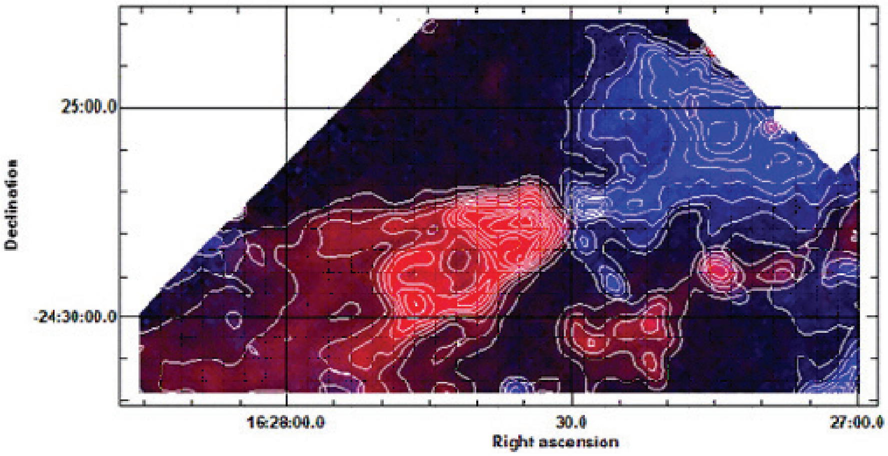

Figure 5. — One of the prominent molecular outflows in Oph B.

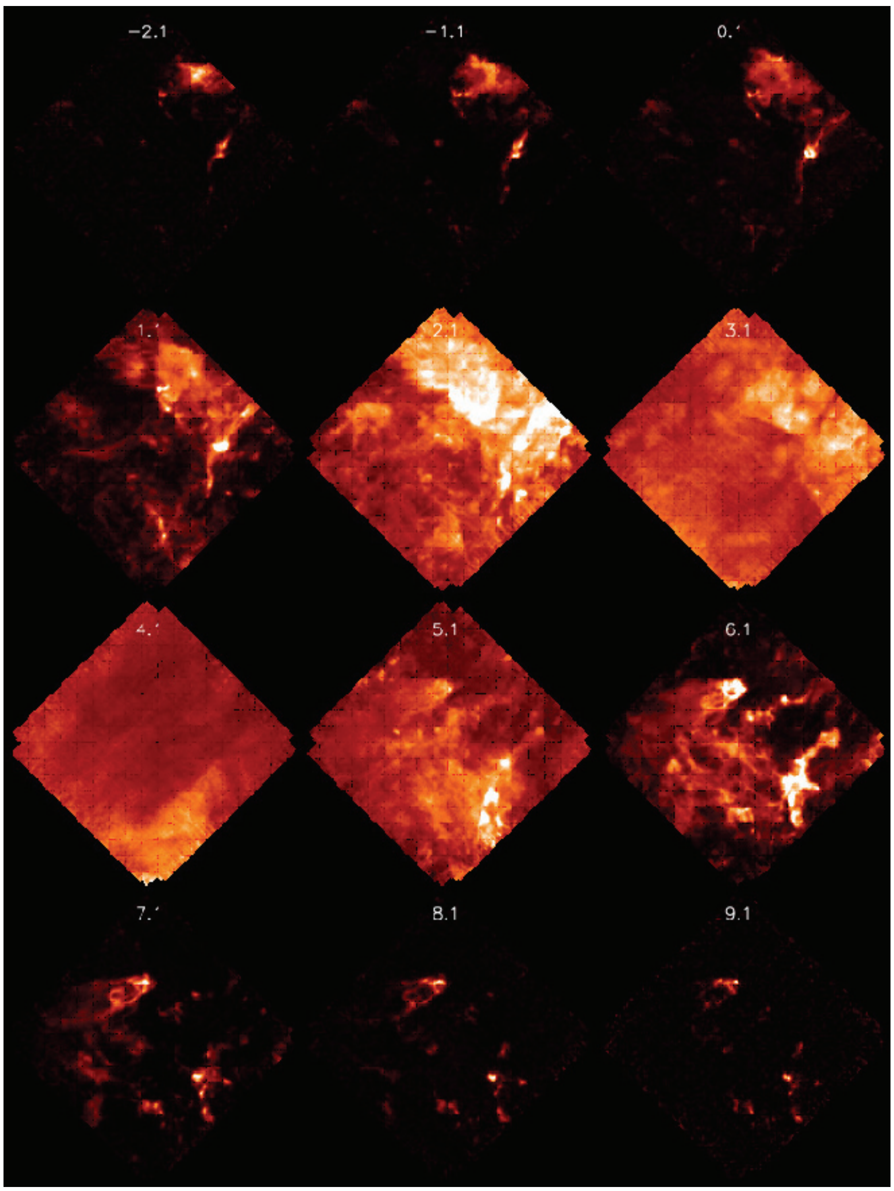

Figure 6. — ^{12}CO channel maps of Oph B

(JLS GBS, continued from page 8)

B-field is perpendicular to the south-east ridge). With combined Spitzer photometry of the proto- and pre-main-sequence stellar populations (*e.g.*, Luhman et al. 2006), GBS ^{13}CO, C^{18}O and SCUBA-2 maps of the compact molecular cores, and narrow-band WFCAM H_2 images and CO 3-2 maps of the jets and outflows, we will associate protostars with cores and outflows, and thereby establish what fraction of cores are actively forming stars (which will also give the statistical lifetimes of the pre-stellar and proto-stellar phases). With high-resolution extinction maps (derived from WFCAM *JHK* photometry), we will also map the large-scale distribution of low-density material, gas which provides 90% of the total mass of a molecular cloud, and investigate how this relates to the distribution of active, star-forming cores.

Ophiuchus

Our initial GBS survey region has mapped the Oph B region just south of the better studied Oph A core and photon dominated region. The Oph B regions includes a number of 1.3 mm continuum sources without infrared counterparts, which are believed to be very early protostellar candidates. These cores appear to be rather cooler than the Oph A core, and power a complex web of molecular outflows. The JCMT HARP/ACSIS maps in the *J*=3-2 CO line are shown in Figure 4, revealing a complex and highly structured environment, likely modified by outflows and other energetic processes related to Oph A, producing the sharp rims and elephant trunk-like structures seen in the individual channel maps.

One of the more prominent molecular outflows in the mapped region is shown in its red and blue shifted line wing emission extending over more than 10' (0.4 pc at a distance of 120 pc) in Figure 6. The distribution of the CO wing emission is highly clumped, suggesting episodic outflow bursts.

(JLS GBS, continued on page 10)

First Science Results from the JCMT Nearby Galaxies Survey (NGS)

Christine Wilson (*McMaster*), Frank Israel (*Leiden*), Stephen Serjeant (*Open*), Bradley Warren (*McMaster*), George Bendo (*Imperial*), & The JLS NGS Consortium

Star formation is arguably the single most important process that drives galaxy evolution. Star formation ultimately enriches both the interstellar medium and intergalactic medium with metals and continually changes the balance between the amount of gaseous material and the number of stars within galaxies. While we know from studying our own Galaxy that stars form in molecular gas, sensitive, wide-area images of molecular gas in galaxies have, until recently, been difficult and time consuming to obtain. Thus, a key piece of the puzzle in understanding star formation laws has been missing. By obtaining sensitive CO J=3-2 images of 155 galaxies within 25 Mpc, this JCMT Legacy Survey will provide a wealth of data on the molecular gas content and properties of galaxies of all morphological types. This article describes some recent science results from the NGS.

Gas Depletion Times in Virgo Cluster Spirals

The NGS sample includes four large spiral galaxies in the Virgo Cluster (NGC 4254, NGC 4321, NGC 4569, and NGC 4579) which are also part of the SINGS survey (Kennicutt et al. 2003). In the first paper from the NGS (Wilson et al. 2009), we have combined the CO J=3-2 data with published CO J=1-0 data, 24 μm, and Hα images to study the CO line ratios, molecular gas masses, and instantaneous gas depletion times in these galaxies. The first three galaxies have molecular gas masses from 0.7–3×10^9 $M_\odot$ and gas depletion times of 1.1–1.7 Gyr. The CO J=3-2 emission shows a better correlation with the star formation rate surface density than the CO J=1-0 line, both within and between galaxies. We argue that this is because the CO J=3-2 line is tracing the denser molecular gas that is more directly involved in the star formation process.

There are some interesting differences between the galaxies in our sample. NGC 4254, which is probably on its first pass through the Virgo Cluster, appears to have a larger star formation efficiency (or conversely, a smaller instantaneous gas depletion time) than the other two galaxies. NGC 4569 shows a large-scale gradient in the CO J=3-2/J=1-0 line ratio, which implies a similar gradient in the gas temperature or density. NGC 4569 has been shown to be affected by its interaction with the intracluster medium, and our results show that this interaction is also affecting directly the dense star-forming gas. The fourth galaxy in our sample, NGC 4579, is only marginally detected in CO J=3-2 despite having bright nuclear emission in Hα and 24 μm; however, much of the central luminosity of this galaxy may be due to its AGN rather than star formation.

Star Formation Laws in Three SINGS Spirals

Brad Warren (McMaster University) has been carrying out an analysis of three additional galaxies common to both the NGS and the SINGS sample (NGC 628, NGC 3521, and NGC 3627; Warren et al., in preparation). These galaxies have also been studied at high angular resolution in H I as part of the THINGS survey (Walter et al. 2008). NGC 628 is an isolated late-type spiral with a very extended H I disk (see Figure 1), NGC 3521 is a flocculent spiral galaxy, and NGC 3627 is an active barred spiral galaxy that is a member of the Leo triplet. Comparing the H I and CO kinematics using the first moment maps shows some quite significant offsets between the two gas components in some parts of the disk. These offsets are likely due to the H I moment maps not always tracing the rotation curve in the disk due to the presence of extraplanar gas that can be seen as "beards" in H I position-velocity plots (see also de Blok et al. 2008). The velocity dispersion of the CO line is systematically less than that of the H I emission.

We have used the data to investigate the properties of the star formation efficiency as a function of various quantities on a pixel by pixel basis within the three galaxies. We do not see any correlation of the star formation efficiency with the gas sur-

(JLS NGS, continued on page 11)

(JLS GBS, continued from page 9)

This coming year will be a busy one for the GBS team. Oph A and Ori A are now scheduled for HARP/ACSIS observations, with the latter already started in C^{18}O/^{13}CO, extending the work begun by the instrument team. We have plenty of work to do in analysing our existing datacubes: because of the 3-dimensional nature of spectral line mapping, the volumes of data we have in hand from HARP/ACSIS are not that much smaller than we expect from our SCUBA-2 survey, and we have spent much of 2008 getting to grips with the new data reduction software. This year should see some real progress on extracting the science from this exciting survey, and the publication of our first-look papers on these regions.

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face density; this is similar to the results in Leroy et al. (2008), where the star formation efficiency is found to be constant within a factor of two at scales of 800 pc. Similarly, we find that the star formation efficiency is flat or slightly declining as the CO J=3–2/J=1–0 ratio increases. This result is in contrast to the work of Muraoka et al. (2007) who found a correlation between star formation efficiency and line ratio in the starburst galaxy M 83. However, their data span a much smaller range in line ratio than ours, and so their correlation may be spurious.

PAH, MIR, and CO Emission in NGC 2403

George Bendo (Imperial) has been examining the relation between CO J=3–2 emission and mid-infrared polycyclic aromatic hydrocarbon (PAH) emission in the nearby flocculent spiral galaxy NGC 2403 (Bendo et al., in preparation). Previous work has suggested that PAH emission may be good tracer of the cold interstellar medium (Regan et al. 2006, endo et al. 2008). The radial profiles of the PAH and CO J=3–2 intensities are quite similar in NGC 2403. However, the value in the nuclear

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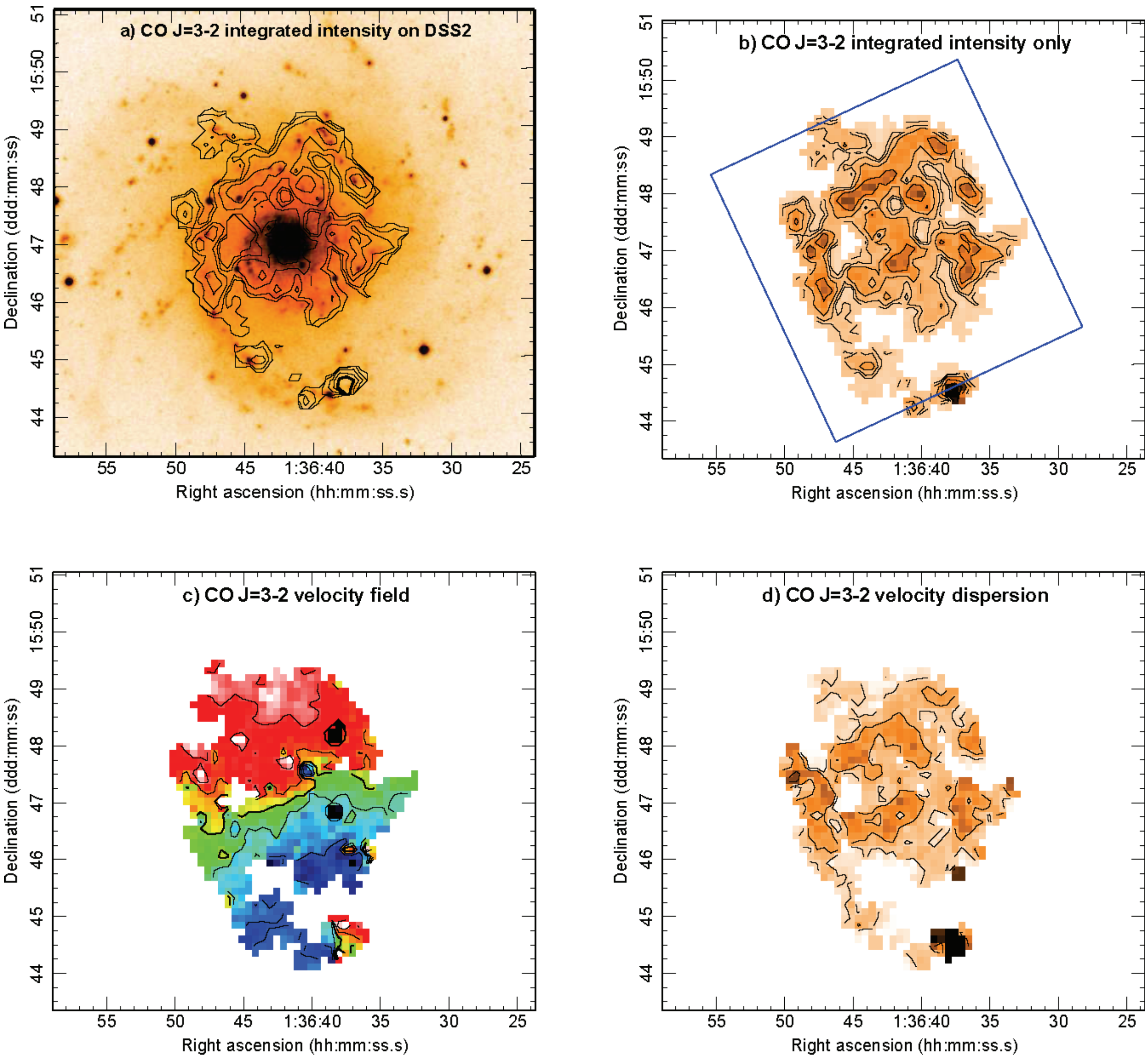

Figure 1. — ^{12}CO J=3–2 moment maps of NGC 628. (upper-left panel) Integrated ^{12}CO J=3–2 intensity distribution (moment 0) contours for NGC 628 overlaid onto an optical DSS II R band image. Contour levels are 0.125, 0.25, 0.5, 1, and 2 K km/s (T_A^*). (upper-right panel) Integrated ^{12}CO J=3–2 intensity contours as in first panel but with our ^{12}CO J=3–2 in the background instead of the DSS II image. White is low (or blank), and black is high. The blue box in this panel shows our target mapping region. (lower-left panel) ^{12}CO J=3–2 velocity field (moment 1) for NGC 628. Contour levels (from blue to red end) are 636, 646, 656 (thick contour, systemic velocity), 666, and 676 km/s. (lower-right panel) ^{12}CO J=3–2 velocity dispersion map (moment 2) for NGC 628. Contour levels are 2 and 4 km/s.

First Science Results of the JCMT Spectral Legacy Survey (SLS)

Floris van der Tak (SRON), Matthijs van der Wiel (SRON/Groningen),
Helen Roberts (Queen's Belfast), Gary Fuller (Manchester), René Plume (Calgary),
Volker Ossenkopf (SRON/Cologne), Marco Spaans (Groningen), & The JLS SLS Consortium

The Spectral Legacy Survey aims to make an inventory of the chemical composition of star-forming environments, for which the current generation of JCMT instruments is superbly suitable. The survey uses the 16-pixel HARP array to image 2'×2' fields around selected targets at 15" resolution, and uses the ACSIS correlator to cover the entire 330–362 GHz window in only 21 frequency settings, while retaining a spectral resolution of better than 1.0 km/s. With target noise levels of 20–25 mK per spectral channel, the SLS is as deep as or deeper than any previous or ongoing spectral survey at any other (sub)millimeter telescope. Furthermore, this sensitivity is good enough to detect lines of isotopically substituted molecules, which is critical for reliable estimates of column densities and abundances, and also useful to address chemical fractionation.

The sources are selected to cover a wide range of star-forming environments. They are: (1) the Orion Bar, a photon-dominated region; (2) NGC 1333 IRAS4, a region of low-mass star formation; (3) AFGL 2591, a region of high-mass star formation; and, (4) W49A(N), a very luminous region of clustered star formation. Although much of the JCMT–SLS science awaits completion of the survey to the target noise level, the consortium has identified several "forerunner" scientific projects which only need data on bright emission lines which can be unambiguously identified. This article describes some of the first science results that are coming out of the SLS, and outlines our plans for the near future. Further details about the setup of the survey can be found in Plume et al. (2007).

Chemical Stratification in the Orion Bar

One of the regions studied in the SLS is the Orion Bar, a ridge of molecular material illuminated from

(JLS SLS, continued on page 13)

(JLS NGS, continued from page 11)

region is quite different from that of the disk and a detailed comparison of the two images show that they do not correlate perfectly on small spatial scales.

This analysis has been extended to investigate the association of dust with atomic and molecular gas on kiloparsec scales. In this galaxy, most of the mass of the interstellar medium is in the form of atomic gas. The H_2 radial profile is significantly less extended than that of the dust, while the atomic gas is nearly constant with radius. These profiles produce a gas to dust ratio that increases with increasing radius, possibly driven by the known decrease in metallicity with radius in this galaxy.

Extremely Low Velocity Dispersions in the Molecular Gas

During Brad Warren's analysis of the three galaxies from SINGS, we noticed that one of the galaxies, NGC 628, had extremely small values for the velocity dispersion in the CO J=3–2 emission (see Figure 1). It turns out that this galaxy is very close to face-on and so is an excellent target for measuring the velocity dispersion in the interstellar medium essentially free from broadening due to large-scale rotation. Chris Wilson (McMaster University) has been examining all the galaxies observed to date in the NGS with inclinations less than 60° (Wilson et al., in preparation) for comparison with similar H I results published in Leroy et al. (2008). The raw velocity dispersions in the 6 galaxies with good CO detections range from a low of 2.7 km/s in NGC 628 to a high of 9.0 km/s in NGC 4254. These dispersions are sufficiently small that it is important to correct for the internal velocity dispersion of individual molecular clouds, which in our own Galaxy range from 1–8 km/s (Solomon et al. 1987). Correcting for this leads to a cloud-cloud velocity dispersion of just 5 km/s. Such a small velocity dispersion, which is on average a factor of three or more smaller than the velocity dispersion of the atomic gas, implies a very small scale height for the molecular component.

Future Work

In addition to the projects described above, the NGS team wiki lists six additional projects focusing on detailed studies of the individual large galaxies in the NGS, most of which involve Ph.D. students. In addition, Frank Israel is planning a paper on the statistics of the circumnuclear CO concentrations using the entire sample, and graduate student Jen Golding at McMaster will focus on a comparison of the properties of the Virgo Cluster and field galaxies. Chris Wilson is beginning to plan for an overview paper of the entire HARP/ACSIS portion of the NGS which will likely focus on the correlation between CO J=3–2 luminosity and far-infrared luminosity to try to pin down the behavior of the relation seen in Iono et al. (2009) for normal galaxies.

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one side by intense UV radiation from young massive stars. This irradiation produces a layered structure: a hot region of ionized atoms on the side of the cloud facing the UV radiation, and colder layers of various molecular species deeper into the cloud. Van der Wiel et al. (2009) have used the JCMT-SLS data to refine our view of the chemical stratification pattern which accompanies the physical stratification of the Orion Bar. The C_2H radical is seen close behind the ionization front, followed by the H_2CO and SO molecules somewhat further in, while ^{13}CO, $C^{18}O$ and HCN reside in the cold gas deep inside the cloud (see Figure 1).

A numerical model of the gas temperature and chemical composition as a function of depth into the cloud reproduces the observed stratification pattern qualitatively, although SO peaks deeper than observed and H_2CO peaks closer to the ionization front than observed. The main shortcoming of the model seems to be that it only considers gas-phase chemistry, as shown by three effects. First, the observed H_2CO abundance is higher than in the model, which suggests that the observed H_2CO is mainly produced by evaporation of icy grain mantles. The observed C_2H abundance is also higher than in the model, which indicates that a significant source of C_2H is the photo-destruction of PAH molecules, which have their peak emission close to the ionization front. Third, the SO abundance in the model is orders of magnitude higher than observed, which implies an overall depletion of gas-phase sulphur by several thousand. The low sulphur depletion observed recently in the Horsehead nebula (Goicoechea et al. 2006) thus does not seem to apply to the entire Orion region, but appears instead to

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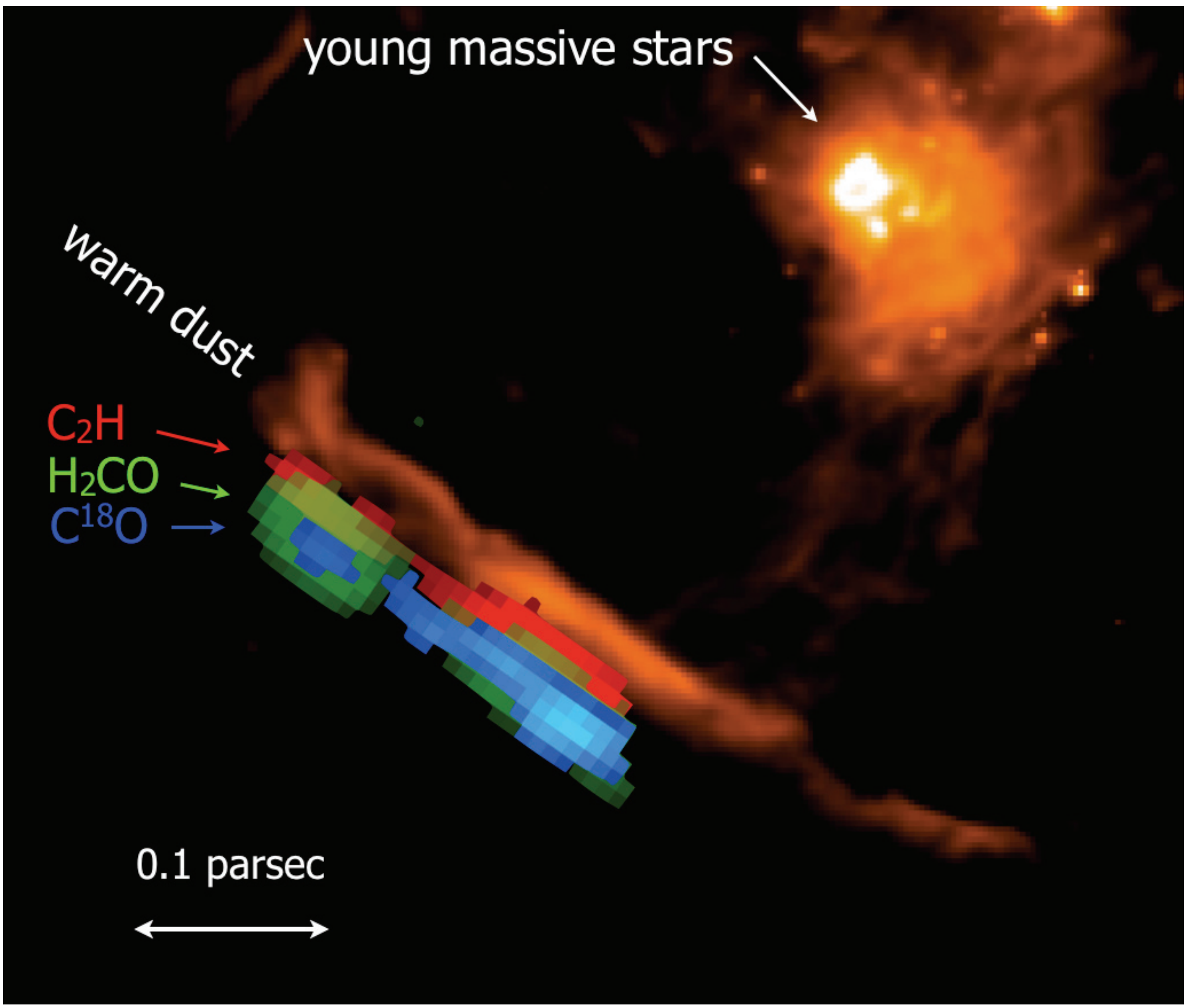

Figure 1. — Chemical layering in the Orion Bar, as observed in the JCMT-SLS data. UV photons emitted by young massive stars impinge on the molecular cloud and give rise to a layered structure. Orange is the Spitzer 8 μm image, and red/green/blue are JCMT images of C_2H, H_2CO and $C^{18}O$ submm line emission. Based on: Van der Wiel et al. 2009, A&A, in press.

(JLS SLS, continued from page 13)

depend on local conditions such as the gas density.

The HCN and HCO$^+$ Molecules as Tracers of Star Formation

The second "early result" from the SLS data is a comparison of HCO$^+$ and HCN emission from the SLS sources, which is an effort by Roberts et al. (2009, in preparation). The HCO$^+$ and HCN molecules are often used as tracers of (extragalactic) star formation, and the idea of this work is to see how valid this assumption is. One particular question is to what extent HCO$^+$ and HCN are in fact tracing the same gas, in terms of kinematics, spatial distribution, and excitation. Preliminary comparison indicates that the spatial distribution of HCO$^+$ and HCN is quite similar, at least on scales probed by JCMT–HARP/ACSIS (see Figure 2). In the near future, we will combine the SLS data with existing JCMT A-band data for these sources, and data of the 1–0 lines from the literature. Extragalactic observers often only have access to the ground-state lines, although observations of high-*J* lines are becoming available for specific galactic nuclei. We wish to explore how a limitation to low-*J* lines affects the derived physical conditions, and to study the HCO$^+$ to HCN ratio as a function of *J*-level.

Future Plans

The acquisition of SLS data is expected to be completed by the end of 2009. Whereas the "first results" papers described above only use the brightest emission features in the spectral maps, which can be unambiguously identified, the SLS data will only reveal their full power when the spectra are complete. With this data set in hand, the SLS team will make an inventory of the chemical composition of each of the five SLS sources. For many molecules, the spectra will show multiple lines, which will help to constrain their excitation and thus improves the reliability of column density and abundance estimates. The consortium plans to publish at least one paper per source describing the data and providing estimates of the molecular composition of the gas. Follow-up papers will then compare the results for different sources and identify chemical evolution patterns.

Analysis of the line data will proceed at several levels of sophistication. On a basic level, rotation diagrams and full-spectrum LTE models will be used to verify line identifications and check their consistency. At an intermediate level, non-LTE single-point models will be used to derive first-order estimates of molecular column densities. At the highest level, physical and chemical models will be coupled to full radiative transfer calculations to derive the full source structure. In 1-dimensional and 2-dimensional modeling, the radiative transfer will be non-LTE; for 3-dimensional modeling, non-LTE is the goal, but it may be necessary to assume LTE in order to limit the number of free parameters. The temperature and density structure of the SLS sources are currently being derived from submillimeter continuum images and will serve as input to the radiative transfer calculations. Simultaneously, chemical models are being developed to interpret the results of the abundance estimations. Several types of chemistry, such as shocks and hot cores, are being considered, as well as the effects of irradiation by UV light (PDRs), X-rays (XDRs) and cosmic rays. The spatial information of the SLS data allows us to study variations of physical and chemical conditions as a function of position within the sources.

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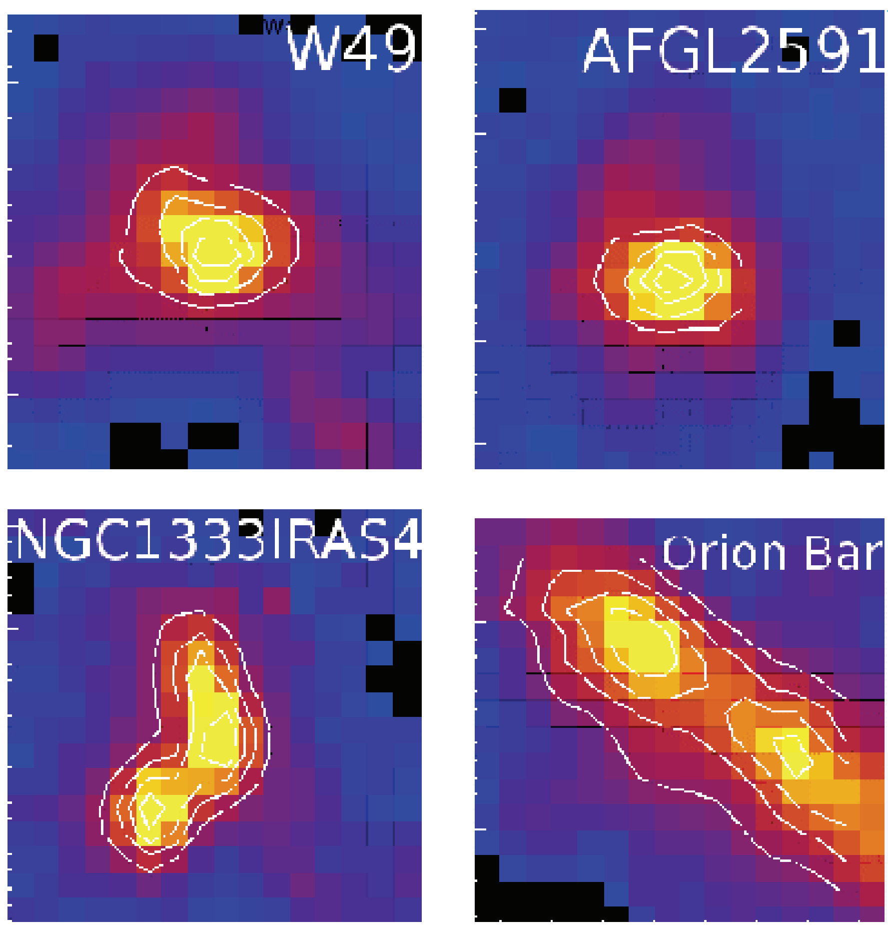

Figure 2. — Maps of velocity-integrated HCN J=4–3 emission towards the JCMT-SLS sources. The field size is 2×2 arcmin. Based on: Roberts et al. 2009, in preparation.

Celebrating the International Year of Astronomy, Hawaiian Style

Inge Heyer (*JAC Science Outreach Specialist*)

As many readers will know, 2009 is the International Year of Astronomy (IYA). Many public events are planned in 140 nations around the globe, to celebrate astronomy, to raise the awareness of the general public, and to engage students of all ages. The observatories on Mauna Kea in Hawaii are participating in many of the global events, and they also put on a few of their own. Some are annual events that have a special IYA theme this year, others are one-off events just for this year. JAC's UKIRT and JCMT staff are participating in all of these.

IYA 2009 started off with the Onizuka Science Day in January, an annual event, but standing this year definitely in the light of international astronomy. This day honors Hawaii's astronaut Ellison Onizuka, who perished in the space shuttle Challenger. School children of all ages are invited to spend the day at the University of Hawaii in Hilo to learn about various science disciplines. JAC staff presented a workshop on extrasolar planets, which allowed the students to build their own solar systems.

One of the most involved annual outreach events on the Big Island of Hawaii is the Journey through the Universe. Astronomers and engineers from all observatories go into the schools for one week to teach classes. This year 55 astronomers visited over 8000 students in the local school district. There were six staff from JAC among them, talking about and demonstrating a variety of subjects, all related to activities around astronomy. Journey is not only about the class room visits, even though that is its focus, but it also includes community activities and lectures at our local science centre. For the first time this year Journey featured two parallel sessions at the local book store: an astronomy story time for little ones, and a science cafe discussion forum for the adults.

The teachers in the public, private and charter schools are often asking not only for astronomers to visit their class rooms, but also for them to be a resource for astronomy knowledge. Therefore it seemed a good idea to hold an astronomy class for teachers, giving them the knowledge to teach the subject in their class rooms. Funding was requested and received to teach a special one-year once-a-month introductory astronomy class for teachers. Unlike a regular class at the university, where the goal is to cover the whole text, this class focuses on key concepts and builds hands-on activities around them. The teachers do the exercises in class, and then they can take the materials and do it with their own students in their classes. This class is free of charge to the teachers, since both the classroom facilities and the text books have been donated. This class is organized and taught by JAC staff.

Throughout the year there are a number of science and career fairs in our community, organized by the school district or individual schools, all geared towards introducing the students to careers in the sciences, engineering and technology. JAC staff, including this year's high school student intern, participated in a number of these during the first third of this year, and there will be many more to come during the rest of the year.

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