JAMES CLERK MAXWELL TELESCOPE
APPLICATION FOR TELESCOPE TIME

Read 'The JCMT Newsletter' on the the World-Wide-Web (http://www.jach.hawaii.edu) for up-to-date information	For office use only REF:-

1 **Semester: 03A** (last 2 digits of year, followed by 'A' for Feb – Jul; or 'B' for Aug – Jan semesters)

2 i) Principal Investigator:

Surname	Title & Initials	Possible Observer?
Johnstone	**Dr. Doug**	**YES**

Address
NRC-HIA
5071 West Saanich Rd
Victoria BC V9E 2E7 Canada

Full Internet E. Mail address: doug.johnstone@nrc.ca
Fax: 250 363-0045
Telephone & Ext: 250 363-8108

ii) Collaborators (state institution and country)

Collaborator	Possible Observer?
James Di Francesco NRC-HIA Canada	YES
Alyssa Goodman, Scott Schnee Harvard USA	YES
Rachel Friesen, Christopher Capobianco Victoria Canada	YES
The Rest of the COMPLETE SURVEY Team	

Student Thesis Project? no
Completion Date?

3 TITLE AND STATUS OF INVESTIGATION YOUNG STARS AND CIRCUMSTELLAR MATERIAL
SCUBA-mapping thermal emission from cold dust: part of the COMPLETE Survey of Star-forming Regions

4 ABSTRACT OF PROPOSED OBSERVATIONS
The COMPLETE survey comprises COordinated Molecular-Probe line, Extinction, & Thermal Emission observations of three star-forming regions (Ophiuchus, Serpens, & Perseus) scheduled to be extensively observed with SIRTF. No previous survey has covered a single ~10 pc region comprehensively. The statistical constraints offered by this survey will be of great interest to both the Milky Way and high-redshift star formation communities. SCUBA is the optimal instrument for obtaining the large-area, sensitive submm dust thermal emission maps required for COMPLETE. The SCUBA survey will be over an order of magnitude larger than previous submm molecular cloud maps (~10 sq.deg), detecting hundreds, possibly thousands, of new sources, many without near-IR or molecular line counterparts. The uniformity of the COMPLETE Survey will allow direct comparison between these clumps and the cloud conditions. *The SCUBA survey is partitioned over 2 semesters, with 80 hours requested in each.*

5 LONG TERM STATUS: YES If yes, give total number of useful shifts needed to complete programme: 20

6 RECEIVERS:

	○ A-band	○ B-band	○ C-band	○ D-band	⊗ SCUBA	○ Other	○ Pol'n	○ SBI
	208-280 GHz	315-373 GHz	430-510 GHz	625-710 GHz	continuum camera		het/scuba + pol.	Interferometry
# HOURS:					160			

7 DETAILS OF OBSERVING TIME
i) Total number of hours requested: 160   ii) LST Range:
iii) Flexible Scheduling ○ NOT wanted
iv) Required Weather Quality ○ 1 (very dry) $\tau_{225} < 0.05$ ⊗ 2 (dry) $0.05 < \tau_{225} < 0.08$ ⊗ 3 (medium) $0.08 < \tau_{225} < 0.12$ ○ 4 (wet) $0.12 < \tau_{225} < 0.2$ ○ 5 (very wet) $\tau_{225} > 0.2$

8 LIST OF PRINCIPAL SOURCES (exact coordinates required, continue on Figs & Tables page if necessary)

Name	RA (hh mm ss)	Dec (dd ' ")	Epoch	Intens.	Priority
Ophiuchus	16 30	-25 00	J2000		1
Perseus	03 30	32 00	J2000		1
Sepens	18 30	01 00	J2000		1

9 RELATED APPLICATIONS (over last 4 semesters (include unsuccessful applications))

Complete Ref (ie: M/94A/U22)	Allocated	Useful Shifts	Comments

10 JUSTIFICATION (Add no more than 1 page for each of Scientific case + Technical details + Figures & Tables. Long-term proposals are permitted up to two pages for the Scientific case.)

SUBMISSION OF APPLICATIONS

Electronic Submissions:

CANADA: Attach completed postscript and latex files to the respective email address below.

UK & INTERNATIONAL: Send the latex template and completed postscript files (concatenated into one file) to the email address below. The SUBJECT line of the email submission must say **NEW SUBMISSION UK** or **NEW SUBMISSION INT** for UK and International proposals respectively. UK proposers must complete the separate signatures page and send by regular mail or courier to the address below.

NETHERLANDS: Send the latex template and completed postscript files (concatenated into one file) to the email address below. The SUBJECT line of the email submission must say **NEW SUBMISSION NL**

Latex templates, style files and instructions may be obtained by sending the message *request templates* to "jcmtprop@jach.hawaii.edu".

Hardcopy Submissions:

Please submit 8 copies of the proposal to the appropriate national/international TAG below (except for Canada or Netherlands). (Please consult the JCMT Web pages at http://www.jach.hawaii.edu for rules regarding "partner" countries.)

CANADA	**NETHERLANDS**	**UK & International**
hardcopy proposals not accepted	hardcopy proposals not accepted	PATT Secretariat Particle Physics & Astronomy Research Council Polaris House Swindon SN2 1SZ UNITED KINGDOM
jcmtweb@nrc.ca	proposal@nfra.nl	jcmtprop@jach.hawaii.edu

CLOSING DATES

'A' SEMESTER: FEBRUARY – JULY
Applications must be received by:
30 SEPTEMBER

'B' SEMESTER: AUGUST – JANUARY
Applications must be received by:
31 MARCH

SCIENTIFIC JUSTIFICATION

COMPLETE Overview: The goal of the COordinated Molecular-Probe line, Extinction, & Thermal Emission Survey of star-forming regions is to use a carefully chosen set of observing techniques to fully-sample the density, temperature, and velocity structure of three large nearby star-forming complexes (Ophiuchus, Perseus, & Serpens) to be observed in the SIRTF Legacy Survey "From Molecular Cores to Planet-forming Disks." The Legacy Survey, scheduled for 2003, will provide high-resolution IR spectroscopy, and near- through far-IR images of each ~10-pc-scale target complex (`peggysue.as.utexas.edu/SIRTF/`). COMPLETE will provide fully-sampled molecular spectral-line, extinction, and thermal emission maps for the same regions, at arcminute resolution or better (`cfa-www.harvard.edu/~agoodman/research8.html`). COMPLETE will also include higher-resolution observations using the same techniques for a large subset of the high-density cores evident at lower resolution. COMPLETE's molecular-line observations provide the essential kinematic context for interpreting the SIRTF Legacy data; and COMPLETE's extinction mapping is designed to offer the best possible column-density calibration for the SIRTF Legacy data. *The thermal emission* **SCUBA** *survey will find hundreds, possibly thousands, of new sources, many undetected in the near-IR or molecular line data, allowing for both a determination of the physical conditions within each clump, and investigation into the environmental constraints on clump existence.* The COMPLETE project has only become possible in the past few years, and would have been impossible just five years ago.

COMPLETE is unique in its coordinated approach. Only rarely have investigations fully-sampled regions, and no survey has covered a single ($\sim$ 10 pc) star-forming region fully with molecular line, extinction, and dust emission observations. The lack of an unbiased survey like COMPLETE has left star formation theories without statistical constraints on the temporal and spatial frequency of for example: inward motions, outflow motions, star-formation, cloud disruption, core formation, clump clustering, and column density distribution. Such statistical techniques are necessary for analyzing data and providing a meaningful comparison with numerical simulations (e.g. Rosolwsky, **Goodman** et al. 1999). All the COMPLETE data will be made publicly available on the Internet, through an already-funded NVO program at the CfA (`cfa-www.harvard.edu/~agoodman/research11.html`), within one year of acquisition. We expect the statistical constraints offered by the COMPLETE Survey to be of great interest to both the nearby and extra-galactic star formation communities.

The COMPLETE team includes experts in all of the diverse observing methods to be used in the Survey. We have already completed pilot observations for the molecular line survey, and the full FCRAO survey will begin this winter (see `cfa-www.harvard.edu/~sschnee/complete/complete.fcrao.sep2002.pdf`). Extinction mapping (both IRAS and 2MASS-based) is well underway, and an extensive literature search for existing observations of the target regions has been completed (see the COMPLETE web site).

COMPLETE Components: The target regions (Ophiuchus, Serpens, and Perseus) for the COMPLETE Survey were chosen from the SIRTF Legacy Project. The Evans et al. SIRTF Legacy Survey will map out these complexes in far-infrared emission and take a full (near-IR) census of the energetic sources. SIRTF spectroscopy will yield information on the mass, age, luminosity, and disk properties of many of these sources. The 70 μm SIRTF maps will provide the shortest wavelength component of the COMPLETE Survey. However, the long-wavelength SIRTF detectors will completely saturate making ground-based submm data crucial. *Combined with the* 70 μm *maps, the* **SCUBA** *survey will probe the thermal emission of embedded sources across the peak of their SED allowing a much more precise measure of both the temperature and density distribution. Thus, the submm maps obtained with* **SCUBA** *will play a crucial role.* Since SIRTF observations provide information only on the warm environment, a lack of corresponding 850μm flux in a SIRTF source will imply a more evolved or cleared out region, while an 850μm source without corresponding SIRTF flux will imply a cold, precollapse environment.

All other relevant ancillary data are being tapped by COMPLETE. In particular, the 2MASS catalog provides a uniform data set for producing extinction maps of the chosen regions (NICER, Lombardi & **Alves** 2001). Combined with near-IR SIRTF data and follow-up ground based 8-m observing, this technique allows for extinction mapping with both a very high spatial resolution and an unprecedented dynamic range in scales. The resulting extinction maps provide a calibrated column density measure within each molecular cloud. *The* **SCUBA** *survey results will allow definitive temperature measurements of the condensations as well as a detailed analysis of their physical structure* (e.g. B68 **Alves**, Lada, & Lada 2001).

Pilot FCRAO observations using the new SEQUOIA array were obtained in April 2002. These results, shown in Figure 1, proved that it is now possible to map (with full spatial sampling) cloud complexes to $A_V > 1$ in both ^{13}CO and ^{12}CO 1–0. A long-term proposal covering the three COMPLETE clouds (21 observing days) was submitted in 2002 September to FCRAO with strong encouragement from its Management. These data will provide kinematic information on all density enhancements likely related to star formation in each of these nearby molecular clouds. For example, ^{12}CO data will trace high velocity gas from all outflows in these regions while ^{13}CO data will trace systematic motions of the clumps within these regions. *The* **SCUBA** *survey is needed to properly detect many of these clumps. Since* CO *freezes-out at high densities and low temperatures* (e.g. **Caselli** et al. 1999; **Tafalla** et al. 2002), *the* 850μm *clump structure will reveal sources which are "invisible" in* CO (e.g. Mitchell, **Johnstone**, et al. 2001). Wide-field observations of both the CO and submm clumps in higher density transitions of CS and N_2H^+ are planned for next winter. The sheer number of structures revealed with FCRAO data will allow the completion of the first large-sample statistical studies of velocities in star-forming molecular clouds.

COMPLETEly SCUBA: Only recently have large-area ($\sim$ 0.3 sq.deg) maps of molecular clouds at high angular resolution been obtainable in the submm (Motte et al. 1998; **Johnstone** & Bally 1999; **Johnstone** et al. 2000b, 2001; Motte et al. 2001). **SCUBA** at the JCMT is the optimal instrument for performing these studies, producing a majority of the large-area maps. The dominant feature within these maps is the small-scale clumping of the gas and dust. These clumps, totalling about 10-20 percent of the mass within the larger molecular core, produce a 'clump mass spectrum' showing a slope similar to the stellar IMF. Whether this distribution implies that individual clumps are direct progenitors of stars is hotly debated and cannot be solved by submm data alone. The clumps have been modelled by **Johnstone** et al. as Bonnor-Ebert spheres in an attempt to determine their underlying physical conditions (temperature, stability); however, a lack of shorter wavelength information, and uncertainties in the dust emission properties at submm wavelengths have limited the usefulness of these results. A second result from the large-area mapping has been the spatial distribution of the clumps both in terms of clump clustering and clump location within the cloud. The submm sources are found to cluster within individual molecular cores (**Johnstone** et al. 2000b, 2001) perhaps implying that they fragmented or condensed from these larger, more massive structures. There is also evidence for an environmental importance of the mean extinction through the molecular cloud. Clumps are found predominantly in the densest ($A_V > 10$) regions.

While these previous large-area maps have produced significant results which are challenging the accepted models for star-formation, especially through the now robust measure of the 'clump mass spectrum', the observations have been biased toward the centers of star formation within molecular clouds and in particular, the highest extinction regions. The environmental data explicitly suffers from this. *The* **SCUBA** *survey will produce uniform submm maps of Ophiuchus, Serpens, and Perseus over a much larger scale* ($1-7$ sq.deg), *for completeness to a mean molecular cloud extinction of* $A_V \sim 5$. This will allow for detailed consideration of the effect of environment on clump statistics. The noise level in the maps will be ≤ 45mJy/beam, providing sensitivity to compact sources with column densities greater than $\sim 5\times10^{21}$ cm^{-2} (assuming typical dust parameters and $T_d \sim 20$ K). Some sources will lie beneath this threshold. Comparison with published data by **Johnstone** et al. (2000b, 2001) reveals that about $1/4-1/2$ of their observed sources would be 'missed' by this faster survey; however, the vast numbers found in those maps ($\sim$ 300 per sq.deg) suggest that this SCUBA survey will find hundreds and possibly thousands of new sources.

Many of the newly discovered clumps will have no molecular line counterpart in CO (due to freeze-out) and will serve as targets for follow-up dense-gas tracer observations such as CS and especially N_2H^+, which is known not to freeze-out in cold, dense envelopes. Combined, these data sets will help connect the clumps with their coincident molecular cores. For example, how dynamical is the fragmentation or condensation? Are there signatures of infall near the submm clumps, and if so is the infall localized (**Di Francesco** et al. 2002) or coherent on larger scales (e.g. Mardones, **Tafalla** et al. 1997)?

The SCUBA *survey will compliment the SIRTF near-IR observations, providing a link between the cold dust associated with the submm clumps and any energetic sources within.* Our knowledge of *all* submm observations is severely limited by the lack of coordinated near-IR and submm observations. The COMPLETE Survey will reveal both the necessary environmental conditions for and the clustering nature of the submm sources, required for meaningful statistical analysis. Significant new finds will be targeted for deeper **SCUBA** observations through a follow-up proposal planned for next year.

The COMPLETE Survey offers the JCMT and SCUBA a unique opportunity to contribute to what is almost certain to become a landmark study of star formation. The large time request is aimed at producing an unprecedented data set that will be shared, essentially immediately, with the entire astronomical community.

TECHNICAL DETAILS & REFERENCES

COMPLETE Time and Sensitivity: Scan-mapping with SCUBA on the JCMT is now straightforward. This allows for the telescope to be used very efficiently in the production of large-area submm maps. The typical rule of thumb for scanning is that a one-sigma sensitivity of $\leq$ 30 mJy/beam over a region 10'x10' is obtainable in about one hour of observing (inc. overheads). The limiting speed of these observations is set by the requirement to fully sample the sky at the Nyquist frequency of the short wavelength (450μm) bolometer array. However, in order to obtain data quicker, scan-mapping may also be obtained in a fast-scan mode in which only the 850μm data is Nyquist sampled. Effectively, this doubles the speed of map-making at a cost of $\sqrt{2}$ in sensitivity due to the shorter integration time per location. The result is that a one-sigma sensitivity of $\leq$ 45 mJy/beam over a region 10'x10' is obtainable in half an hour. At this rate, a full square degree will take 18 hours (inc. overheads).

COMPLETE Coverage: We have produced extinction maps for each of the three star-forming molecular clouds in our study using the IRAS 100 and 60 μm observations (technique described in Arce & **Goodman** 1999). Figure 2a shows in grey-scale the level of extinction across the Perseus cloud (see `cfa-www.harvard.edu/~agoodman/research8.html` for links to the other extinction maps). From these maps we have determined that the required coverage to reach a uniform cloud extinction of $A_V \sim 5$ is $\sim$1 sq.deg in Serpens, $\sim$2 sq.deg in Perseus, and $\sim$ 8 sq.deg in Ophiuchus. Thus, we need to map a combined 11 sq.deg, requiring 200 hours. However, a reasonable subset of data already exists in the JCMT SCUBA archive which will be used to decrease our required telescope time. In Figure 2a contours are overlaid enclosing the regions where SCUBA data already have been taken, and the resulting map from one of these regions is displayed in Figure 2b. Thus, for Perseus about half the required data already exist. The same is true for Serpens; however, only a small fraction of Ophiuchus has been measured to date (due to the extreme size of Ophiuchus). In total about 20 percent of the required data already exist and need not be retaken. Thus, we require time to map 9 sq.deg or approximately 160 hours.

COMPLETEness and the Archive: The archive data does not alone provide the required uniform coverage of these star-forming molecular clouds. To produce statistically meaningful correlations between the SCUBA data and the molecular cloud properties derived from extinction mapping, molecular line data, and SIRTF near-IR mapping and spectroscopy, it is necessary to produce large *unbiased* maps of these clouds. In some cases the archived data will need to be *degraded* to the sensitivity of the present survey.

COMPLETE Map-making: The iterative map making technique (described in **Johnstone** et al. 2000a) allows for optimal reconstruction of the inhomogeneously acquired archive data and has been further modified to accommodate jiggle observations as well. Thus, *all* relevant archive data will be seamlessly stitched together allowing for maximum value from the archived data. Providing manpower, three graduate students are named in this proposal. Schnee (Harvard) will produce his PhD thesis from the COMPLETE Survey. Two additional Masters students (Victoria) will aid in both the new data acquisition and the combined data reconstruction. At least one Masters thesis is likely to result from the SCUBA survey.

COMPLETE Observing Strategy: SIRTF launches in January 2003 and the Legacy Projects are scheduled to be completed in the first year. We request 160 hours over two semesters (80 hours each) in order to produce the COMPLETE Survey on a similar timescale. For the sources found in the SCUBA survey to be used as targets for follow-up SIRTF observations, the maps must be completed in a timely manner.

REFERENCES:(Members of the COMPLETE Survey are listed in boldface.)

Alves, Lada, & Lada 2001, Nature, 409, 159
Arce & **Goodman** 1999, ApJ, 517, 264
Caselli, Walmsley, **Tafalla**, Dore, & Myers 1999, ApJ, 523, L165
di Francesco, Wash, Myers, & Bourke 2002, in preparation. **Johnstone** & Bally 1999, ApJ, 510, L49
Johnstone, Wilson, Moriarty-Schieven, Giannakopoulou-Creighton, & Gregersen 2000a, ApJS, 131, 505
Johnstone, Wilson, Moriarty-Schieven, Joncas, Smith, Gregersen, & Fich 2000b, ApJ, 545, 327
Johnstone, Fich, Mitchell, & Moriarty-Schieven 2001, ApJ, 559, 307
Lombardi & **Alves** 2001, A&A, 377, 1023
Mitchell, **Johnstone**, Moriarty-Schieven, Fich, & Tothill 2001, ApJ, 556, 215
Mardones, Myers, **Tafalla**, Wilner, Bachiller, & Garay 1997, ApJ, 489, 719
Motte, Andre, & Neri 1998, A&A, 336, 150
Motte, Andre, Ward-Thompson, & Bontemps 2001, A&A, 372, L41
Rosolowsky, **Goodman**, Wilner, & Williams 1999, ApJ, 524, 887
Tafalla, Myers, **Caselli**, Walmsley, & Comito 2002, ApJ, 569, 815

FIGURES & TABLES

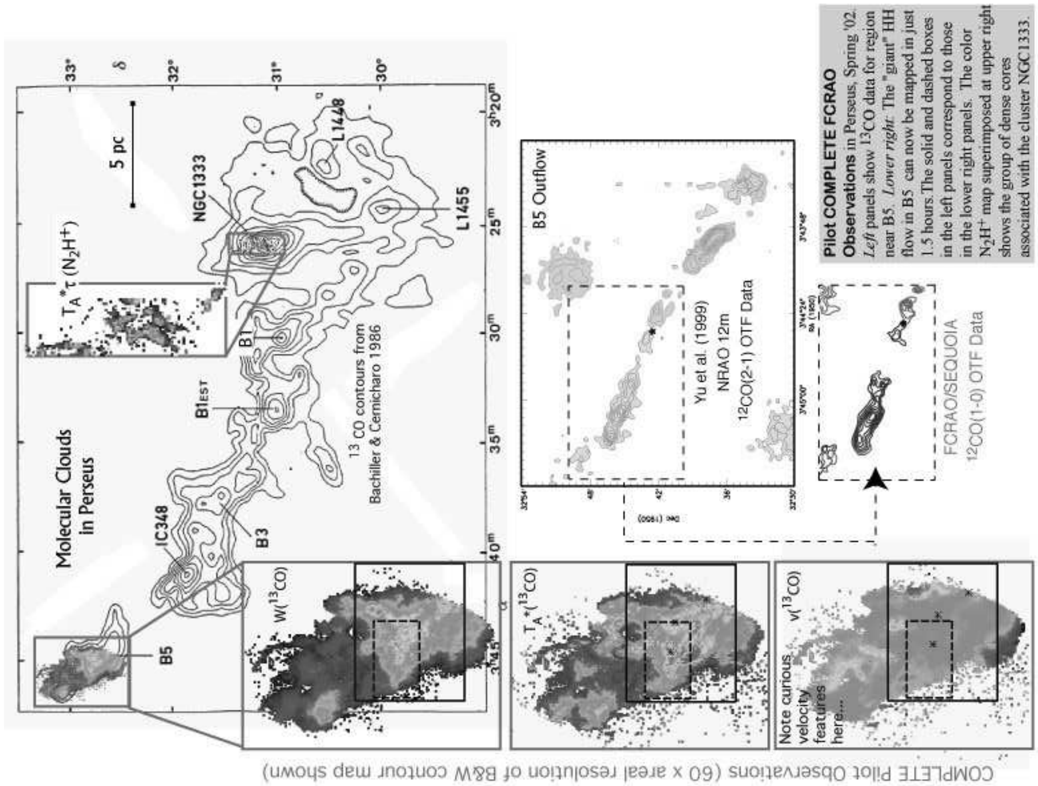

Figure 1: Pilot COMPLETE FCRAO Observations in Perseus, Spring 2002. (Full-sized color image too large for transmission. Available at `cfa-www.harvard.edu/~agoodman/COMPLETE/Proposals/JCMT02/figure1.ps`).

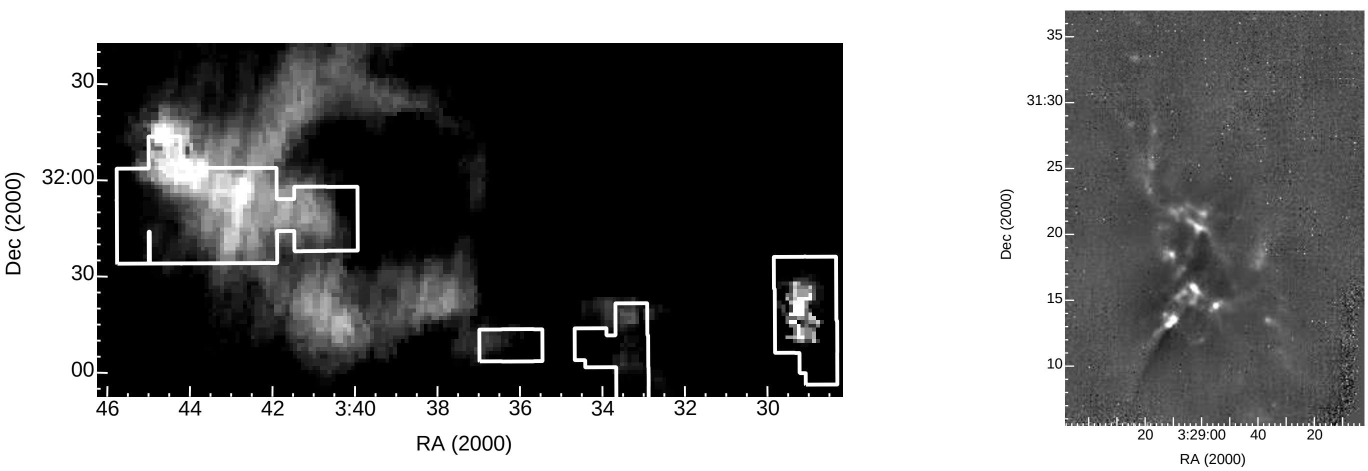

Figure 2: (a-Left) A greyscale image showing the extinction through the Perseus molecular cloud (intensity brightest for $A_V > 10$ visible down to to $A_V \sim 5$). It is our intention to map with SCUBA every non-plack pixel in this map. Contours show regions where the JCMT SCUBA archive has sufficient data for our purposes. About half the required Perseus molecular cloud data exist in the archive. (b-Right) A sample of the data available in the SCUBA archive (NGC 1333 - furthest right contoured region in 2a). The data has only been roughly reduced at this stage; however, it is a simple procedure to gain the data from the archive and perform a complete reduction.