Panel Report from the SCUBA2 FTS Conceptual Design Review
By teleconference, July 30, 2003

Panel:	Don Jennings, Ed Wishnow, Mark Halpern, William Duncan and Per Friberg
FTS team:	Davis Naylor, Brad Gom and Janos Molnar
Notes:	Daphne Summers
Attending	Tim Jenness, Nick Rees, Trevor Hodson, Wayne Holland, Mike Fich (part), Pierre Bastien and Mike Macintosh

Summary
The University of Lethbridge has an impressive experience in the area of building and operating sub-millimeter Fourier Transform Spectrometers (FTS). There is no doubt the group is technical competent to build the planed FTS. However, it is also clear that major work is still pending on optical modeling and better defining observing modes based on the science case. The specific recommendations of the panel are:

- Expand and strengthen the science case. An obvious use of an improved science case is for getting the FTS approved as a JCMT common user instrument by the JCMT Board.
- The science case needs to better define the main science requirements. The discussion indicated that the high resolution is mainly driven by planetary science (relative small sources) while low resolution was anticipated for large area mapping. Such considerations have direct impact on the design and observing modes.
- Select observing modes that can be shown to work, while satisfying the science case, early on in the project. DREAM mode might solve a number of problems but it will not be known if this is the case until the project is well advanced. A failure at that stage could jeopardize the project.
- Consider using a lighter mirror (currently 70kg). It would simplify the mechanical interface and make possible rapid (few Hz) scanning in low-resolution mode. Further, it would make it possible to consider a less power full drive mechanisms, e.g. a loud speaker coil systems, as a compliment.
- There is no need for an early delivery of the FTS for testing SCUBA-2 since there are single pixel FTSes available at Cardiff and other places for testing purposes. Commissioning before summer 2006 is extremely unlikely and a more realistic commissioning time is late 2006.

For the continued work the recommendations are:

- The panel requests that the FTS team first revisit the decision to use a one port setup with the Mach-Zehnder. With the current field of view this looks very hard to accomplish but it might be possible by trading the increased stability and sensitivity for field of view
- Following this the optics need to be modeled in some detail. The panel urges the project to get external help for this.
- During the modeling stage the use of corner cubes instead of roof top mirrors should be considered.

Background
The group at University of Lethbridge 25 years experience in building FTSes. This includes 3 FTSes for the JCMT. The group has now taken on the Canadian Technical lead in the SPIRE project to build an imaging FTS.

The selection to use an FTS was made prior to the CoDR. It selection was based on a number of factors of which some of the more important were; i) detector loading - the SCUBA-2 detectors are designed for a relative high loading level and the FTS is well matched to this level. ii) The interfaces; mechanical, optical and to the data acquisition is simpler for an FTS.

Summary of Discussion

The following is a summary of the discussion. Due to problems with identify/remember who contributed what the contributors are mostly not identified.

Science case/observing modes:

The current science case does not include high redshift galaxies as they were thought to be too week. If a spectrometer was designed from scratch for this purpose a FTS would not been the choice. However, estimates by Wayne indicated it should be possible to detect and get bolometric redshifts to $\delta z \sim 0.1$ using the slope in the 850μm band for a number of sources. Other more sensitive instruments are planned for doing these kinds of observations but these instruments has not the wide field of view. An application for a mode with a wide field of view, high sensitivity (long integration time) and low resolution observing small (not extended) sources.

The other science case that utilize the filed of view is mapping of Galactic Giant Molecular Clouds (GMCs). The advantage of the FTS would be to measure the continuum and line content together. The science goal is to measure the Spectral Energy Distribution (SED) from the continuum shape and determine the line "contamination" level. Sensitivity level missing in the CoDR documents but a few mK is Wayne's estimate. HARP would take over at high resolution, thus this would be wide filed mapping in a low resolution mode observing extended sources. In addition to cores, ridges, filaments and star forming regions GMCs these clouds contains a lower level emission. Such sources are best observed by rapid scanning of the telescope.

The science case also includes smaller sources like Ultra Luminous Infrared Galaxies (ULIRGs) and planetary atmospheres. ULIRGs would not require high resolution. It is planetary tropospheric lines that drive the high-resolution specification. While HARP not would be useful for wide stratospheric lines it could be used for the narrow cores of the lines formed in the troposphere.

Missing from the science case is late type stars, SNR and similar objects. These are somewhat extended objects and an important scientific case would be low-resolution observations to get the SED and line content.

Observing modes issues:

The well-defined band provided by Peter Ade filters makes it possible to "under sample" (it is not really under-sampling, it is using the fact that the sampling theorem specifies a lowest sampling rate of 2*BW not 2*higehest wave number). Utilizing this makes it possible to obtain a high-resolution interferogram to 20 seconds and a low resolution interferogram in 7 seconds. These numbers is a significant improvement over earlier estimates.

The DREAM mode requires a step and integrates mode to be used. The mode needs about 1 second per interferogram point to produce a map. To that the overhead of step and settled down needs to be added. Using "under sampling" about 1000 interferogram points would be needed to get a high resolution. A complete cube (2 spatial + 1 frequency axis) would then be observed in about 20 minutes. In low-resolution mode the time would be of order one minute.

The current JCMT FTS uses one detector. Observing is done by scanning the FTS in about 30 seconds then taking a reference scan off source. The weather is rarely the limiting factor at 850μm. However, the effect is more pronounced at 450μm. Suggestion of methods to correct for atmospheric transmission were using the Water Vapor Monitor (WVM) or using "stray light" falling on the arrays not used by the FTS. Further a system with dual input and dual output port was discussed to some length. Such a system generate outputs of the form

Output Port A $$(Sky + Source)\cdot\frac{(1+\cos(kL))}{2} + Sky\cdot\frac{(1-\cos(kL))}{2} = Sky + Source\cdot\frac{\cos(kL)}{2}$$

Output Port B $$(Sky + Source)\cdot\frac{(1-\cos(kL))}{2} + Sky\cdot\frac{(1+\cos(kL))}{2} = Sky - Source\cdot\frac{\cos(kL)}{2}$$

The detectors integrate these outputs. The result when subtracted is the integral of $Source\cdot\cos(kL)$. The sky emission will not distort the interferogram amplitude. However, transmission changes will still have an effect. A real system would need to consider additional contributions from differences in the "Sky" between the two input ports, differences in the emission not passing the FTS, pixel offsets, and differences in the pixel gains. Some of these problems can be address by also nodding the source between the two input beams.

The focus of the science case is on low-resolution work. This increases the interest in a rapid FTS scan mode. Combing this with raster scanning the antenna is a potential observing mode for GMCs. Rapid FTS scanning is susceptible to noise like 60Hz pickup. Changing scanning speeds can combat this. What will help any observing mode is the lower 1/f noise expected from TES detectors and also the very low 1/f knee of 50mHz.

The DREAM mode has large mirror step overhead (~50% of the total time). By tagging the data packages with the FTS mirror position and status the data reduction should be able to reduce complete DREAM cycles without synchronizing the SMU DREAM pattern with the FTS mirror motion. Of course the FTS mirror needs to stay at each position long enough for a DREAM cycle to complete but the actual phase of the SMU DREAM cycle should not be of importance.

Optics/mechanical design:

The optical design is based on the FTS design for SPIRE. The SPIRE design has been modeled but the SCUBA-2 design has so far not been modeled.

The SCUBA-2 optics has a F/12 focal plane in the cabin, this is followed by a pupil just before the entrance to the elevation tune. The next focal plan (F/7) is at the exit of the elevation tube before the first pick off mirror and beam splitter. Ideally the focal plane should be at the beam splitter to reduce the beam splitter size. As for SPIRE the design includes fixed powered mirrors in the delay line. Thus the roof mirrors are in a parallel region making it possible to focus both arms equally.

The optical design is complicated by the fact the SCUBA-2 cabin optics rotates relative the FTS optics. Further, the SCUBA-2 beam has large aberration at the position of the FTS. Expected to not be a trivial problem to get a good optical performance. The suggested design would use the fixed mirrors to image one beam splitter onto the other.

The optical path varies with the off axis angle. At large optical path differences the variation will become large across a pixel. This effectively limits the spectral resolution. David confirmed that the resolution of $0.005cm^{-1}$ is achievable with the expected filed of view. This agrees just with a simple estimate by Don assuming a Michelson interferometer. Pixels closer to the center of the SCUBA-2 filed of view would perform better.

The field rotation is not rapid enough to cause the image to move a significant amount of the pixel distance in a few minutes. Thus an image rotator is not required.

The issue of using cube corners was discussed. As described they would not add to the thickness of the movable mirror assembly and would help with alignment. However, it was noted that alignment not is a major problem at sub millimeter wavelengths.

DREAM mode

Currently the one-pixel system at the JCMT is using rapid scanning of the FTS. A scan takes about 30 seconds. The telescope is then moved off the source and another interferogram is obtained. These interferograms are processed and subtracted. A step and integrate mode is also possible but has poorer noise performance. Presumable due to changes in the atmosphere during the longer scan time.

The DREAM mode offers to produce calibrated, transmission corrected images with detector and sky offsets removed each second. . This is done on a grid fixed on the sky so image rotation is not an issue. Combing this with a step and integrate mode of the FTS would produce the spectra of the source emission at each pixel on the image in 20 minutes. The DREAM mode has been demonstrated with SCUBA on the JCMT. It does work in absence of microphonics and other noise contributions. However, the version on JCMT did not due atmospheric correction. Further, it operated on chopped signals with removes DC levels. How well DREAM will work with SCUBA-2 in practice is not know yet.

If the DREAM method works but not does a good job on the transmission correction it would be a problem for the FTS. A possible solution would be to use data from the WVM instead. Further, the

DREAM pattern is about 15” wide. The source contribution will be detected as variations across this pattern. Thus it will not be sensitive to an extended smooth contributions. Of course a wider pattern can be crated by scanning the telescope in a Lissajous figure. However, in this mode it might be advantages to scan the FTS fast and the telescope slow i.e. not using DREAM. Another solution would be raster mapping with the FTS scanning fast (perhaps 3Hz). The telescope would raster at a slow speed (< 20”).

Even if DREAM works for SCUBA-2 it might not work well with the FTS. DREAM assumes that the background is smooth over the complete array. Additional gradients or curvatures of this background would cause problems.

As mentioned above the DREAM images is a calibrated image of the sky with sky and detector offsets removed. Thus the resulting is a combination of a number of detectors. Of course the detectors would be from a small area on the array but it would not be straightforward to make any correction for individual detectors. Further the noise would be correlated between pixels.

The mechanism supporting the beam splitters is at room temperature. If an image of these would fall on the array these pixels would see a very different background (and no signal or atmosphere). The array heaters can still be set for the operating part of the array (how would this be done practically by the electronics/firmware?). However, if using DREAM these parts of the array must be masked out. This affect possible operation with the FTS using the center of SCUBA-2 field of view. If the FTS uses one of the sub arrays the room temperature contribution will fall on the other arrays. This would further complicate any use of these arrays for estimating the atmospheric background and transmission.

Other issues

In case the two inputs to the FTS not both are on the sky the unused input will see a background load. If this background temperature not is similar to the sky temperature the power falling on the detectors will vary rapidly at around zero OPD. Even if the TES detectors are able to handle the load they need time to adjust the heaters. This can be solved by scanning slower or by using a suitable load. Of course the atmospheric background is different at 850µm than at 450µm. A dual temperature load would be needed for rapid scanning when both bands are used. The FTS team was of the opinion this would be too much effort to make such a load. The same conclusion can be made from the science case. At 850µm the temperature needed is about 80 K to limited the variation i.e. the load would not be tracking. The sky is not that large contribution to the loading

$$(Sky + Source)\cdot\frac{(1+\cos(kL))}{2} + Load\cdot\frac{(1-\cos(kL))}{2} = \frac{Sky + Load}{2} + (Source + Sky - Load)\cdot\frac{\cos(kL)}{2}$$

More information about the slew rate possible with the detectors is needed.