COMMON-USER SUBMILLIMETRE BOLOMETER ARRAY - 2

SCUBA2

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Contents

Summary

This document presents the requirements for the software necessary for the SCUBA-2 imaging FTS on the James-Clerk-Maxwell Telescope. This instrument will be the most powerful imaging Fourier spectrometer ever built for use in the submillimetre regime, and will take advantage of the extra sensitivity, imaging speed and improved image fidelity of the new SCUBA-2 camera. The general FTS requirements are outlined in the FTS requirements document (SC2/FTS/SYS/001).

Description of the FTS

The SCUBA-2 FTS will be described in minimal detail here to provide background for the software discussion. For more information, the reader should consult the FTS Requirements Document (SC2/FTS/SYS/001) and the FTS OCD (SC2/FTS/SYS/004).

The FTS proposed for use with SCUBA-2 will be of the new Mach-Zehnder design[1] and will be mounted between the left Nasmyth bearing of the JCMT and mirror N1 of the SCUBA-2 optics. The maximum beamsplitter size dictates the field of view of the FTS. The current plan is to provide spectral mapping over one quadrant of the SCUBA-2 arrays (i.e. ~1300 pixels each in the 450 and 850 µm channels). The position of the translation stage will be recorded as a function of the SCUBA-2 master clock to an accuracy of ~ 1 µm and the optical path difference (OPD) corresponding to each pixel's sampled interferogram will be reconstructed during post processing. Once the correct path difference has been assigned to each pixel, standard phase correction and wavelength calibration will be applied.

Principles of operation

The FTS makes use of the mathematical Fourier transform to convert an interferogram into a frequency spectrum. The interferogram is produced by splitting an input beam into two, introducing a difference in optical path between the two beams using a moving mirror assembly, and recombining the two beams where they interfere constructively or destructively as a function of the OPD.

Typically, an FTS is used in 'fast scan' mode, where the moving mirror assembly is moved at a constant velocity, and the detector samples the interferogram on a uniform OPD grid. This requires that the sampling be triggered by the mirror position. An alternative method is to 'step-and-integrate', where the moving mirror assembly is moved by discrete jumps and held stationary at each position while the detector integrates.

With SCUBA-2, frames are read out at a fixed (200 Hz) rate independent of the FTS mirror position. A further complication is that the proposed STARE mode will likely not be practical due to stability issues.[2] We will likely be forced to use the DREAM mode[3], in which the telescope secondary mirror unit (SMU) performs a jiggle pattern for sky correction. This mode has the advantage of producing sky-corrected images, but the disadvantage of only producing corrected frames at a ~1 Hz rate. As a result, the FTS must use a step-and-integrate mode, where the moving mirror is held stationary at discrete intervals of OPD while the DREAM jiggle pattern takes place. Provided that the DREAM mode operates correctly, then the integration time at each position can be made to be long relative to the time to move the mirrors in order to increase observing efficiency.

The resolution of an FTS is determined by the maximum OPD that can be produced, and the sampling interval is determined by the Nyquist theorem. For the SCUBA-2 FTS, with a maximum OPD of ~1.2 m. (~300 mm mirror travel), the resolution will be ~0.005 cm^{-1} and the sampling interval would have to be ~30 μm. Using the DREAM mode frame rate of ~1 Hz, this would require ~2.5 hrs to produce a full resolution scan. This is prohibitively slow, but since the SCUBA-2 filters have excellent out-of-band rejection, we may be able to undersample the interferograms, recover the aliased spectrum in software, and reduce this time by a factor of up to 4 with no loss of resolution.

Software

Fourier spectrometers have the advantage of relatively simple hardware, but the disadvantage of requiring complex data reduction software. The following sections describe the required control and data reduction software for the FTS. A dedicated control PC will handle all FTS I/O and instrument control, while the data reduction software will run within the SCUBA-2 data reduction pipeline. The U of L group has extensive experience designing control and analysis software for Fourier spectrometers, and most of the software required for the SCUBA-2 FTS will be based on a generic processing toolkit in development at the U of L for the SPIRE project.

Control and Acquisition

The FTS control PC will accept commands from the JCMT Observatory Control System (OCS), and synchronize FTS actions using the JCMT Real Time Sequencer (RTS). Before an FTS observation, a sequence of commands must be sent to set the calibration blackbody temperature, move the FTS pickoff mirrors into the SCUBA-2 beam, and check various instrument error conditions. Occasional scans of the SCUBA-2 calibration source must be done to determine the flat field and spectral characteristics of the arrays. During an observation, commands must be sent to position the mirrors in a specific sequence of OPD locations and times. The OPD values must be recorded and time stamped with the RTS interval number by the control PC and sent to the data reduction pipeline for FTS processing.

A motion control unit will provide servo control of the linear motor which drives the moving mirror assembly and the motor that drives the retractable pickoff mirrors. The motion controller will be connected to the control PC via a high speed serial connection. The control PC must interpret the OCS commands and send the appropriate commands to the motion controller, as well as return status values. The control software will also monitor various limit switches and diagnostic sensors on the FTS and report error conditions to the OCS.

The control software must also send operational parameters to the real time display in the control room. These parameters will include items such as the current mirror position and speed, blackbody temperature, instrument limit switch conditions, pickoff mirror position, time remaining, resolution, etc. Parameters will be checked for error conditions and warning messages will be sent accordingly.

Data Reduction and Archiving

A data reduction pipeline for the FTS will be provided by the U of L which takes as inputs the sequence of DREAM corrected images and the associated sequence of OPD values, and produces a spectral data cube as output. The spectral data cube will simply be a stack of frames identical to normal SCUBA-2 frames, except that the frame header will contain a frequency index.

The FTS data reduction pipeline will be based on a generic FTS processing pipeline developed at the U of L, and must run within the main SCUBA-2 pipeline. A list of the main processing modules is as follows:

- **Interferogram Processing**
  - **Quality inspection** – the interferograms must be automatically filtered to remove or flag obvious bad scans, such as where the DREAM mode fails to correct atmospheric fluctuations, etc.
  - **Glitch detection / removal** (if necessary) – The DREAM algorithm should remove cosmic ray spikes, but spurious glitches must be filtered automatically from the data stream. Bad pixels, or saturated signal levels must also be handled.
  - **Gain / atmosphere correction** (if necessary) – If the system gain changes, or atmospheric transmission changes significantly during a long scan, the processing pipeline must correct the resulting signal variation.
  - **Apodization** – The interferograms must be multiplied by an apodization function, which attenuates the data at large OPD values in such a way as to reduce side-lobes in the spectra, and produce an instrumental line shape with desired properties. Details of the apodization function are beyond the scope of this document.
- **Fourier processing**
  - **Phase correction** – Small sampling errors can result in phase distortions in the final spectra. The OPD scale of measured interferograms must be shifted slightly so that data starts exactly at the zero OPD location. Details of phase correction are beyond the scope of this document.
  - **Fourier Transform** – A fast Fourier transform algorithm must be implemented to transform the interferograms into spectra.
  - **Wavelength correction** – Different pixels will likely have slightly different wavelength scales due to the optics of the FTS, which must be corrected by interpolation onto the proper frequency grid.

- **Spectral Processing**
    - **Quality inspection** – The observer must be able to inspect individual spectra in the reduced data cubes to verify that the processing pipeline and instrument are configured properly. Phase correction and apodization failures will be determined by inspection of the measured line profiles.
    - **Spectral Math** (averaging, differencing, etc) – The observer must be able to specify a script that will perform basic operations on a set of observations. Filter characteristics must be corrected for by subtracting background spectra from the source spectra. It must also be possible to average a set of spectra, and stitch data cubes together to produce larger area data sets.

During observations, a simplified quicklook processing pipeline will generate spectra to be displayed on the real time display. The quicklook display must provide at least a single pixel spectrum that is updated continuously during a scan, so that obvious mis-configurations can be trapped as quickly as possible. It would also be desirable to display a continuously updated monochrome map of the source at a specific wavelength or range of wavelengths. The quicklook display would obviously become increasingly accurate as the scan progressed.

If the data cubes are to be stored in single files, the file format must accommodate an array of frequency indices, as well space in the header for FTS parameters such as resolution, blackbody temperature, and other diagnostic values. Archiving could be handled in the same way as standard SCUBA-2 data (as a sequence of individual frames, linked by a frequency index array) or by storing data cubes monolithically.

Testability

a) In preparation for a normal shift: It must be possible to test the functionality of the FTS hardware through a small set of diagnostic commands.

b) As part of routine maintenance: A suite of low level commands must be implemented to allow moving the mirrors, adjusting the blackbody temperature, etc. outside of the normal observing sequences to allow for hardware adjustments and alignment.

c) During development: All aspects of the control and processing software will be tested during development (except for the actual performance of the SCUBA-2 arrays). The processing pipeline modules will be tested as they are developed for SPIRE and other U of L projects, before they are included in the FTS software pipeline.

Responsibilities

Software to control the FTS, as well as the data reduction routines, will be provided by the U of L. Provisions must be made so that suitable FTS commands will be delivered to the FTS control PC, and table position values are recorded with each frame. Significant cooperation will be required with the Data Analysis Software group in order to implement FTS processing in the SCUBA-2 software pipeline.

The FTS processing pipeline will follow JAC coding conventions. Final integration and verification of the FTS processing in the SCUBA-2 pipeline should be done before delivery to the JAC, and will be done by or in close consultation with the Data Analysis Software group.

Dependencies

Information: Software interfaces (ATC, JAC, UBC)
Approval: JAC and ATC will provide final acceptance of the software.
Coding: U of L will provide the coding effort for the FTS control and data reduction software.
Infrastructure: Lab space and time at U of L for initial construction and testing.
Funding: Provided by the CFI budget.

Risks

- Failure of the aliasing mode, which would limit the achievable resolution of the FTS due to time constraints.
- Unforeseen issues with using the DREAM mode in a step-and-integrate scheme.

Development time-line (estimates)

Conceptual Design Review	July 2003
Preliminary Design Review	May 2004
Critical Design Review	October 2004
Complete instrument tests	October 2005
Delivery to telescope	March 2006

These milestones dates are given with the assumption that the current spending freeze for descoping contingency will be lifted by April 2004. Any extra delay in funding beyond this date will result is a corresponding delay in the overall FTS project. The FTS development is organized so that development activities are minimally impacted by the current spending freeze.

In order to ensure seamless collaboration among other teams within the SCUBA-2 development effort, the FTS development process will closely follow the procedures established by the Astronomy Technology Centre in Edinburgh, Scotland and will be accepted by the entire team. See the ATC Project Management Procedures document (189/PMG/01/001) for details.

References

[1] See "An Absolute Dual Beam Emission Spectrometer", Ade et at., *Optical Society of America*, FTS topical meeting poster FWE3, (1999)
[2] See "The SCUBA-2 Flat-Field Problem" (SC2/ANA/S100/43)
[3] "DREAM Algorithms for SCUBA-2" (SC2/ANA/S100/046)