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1.2	28/07/03	Timeline	Adjusted milestone dates

Summary

This document presents the requirements for building an imaging Fourier Transform Spectrometer (FTS) for use with the SCUBA-2 detector system. By combining a spectrometer with the SCUBA-2 detector array it will be possible to obtain, simultaneously, a spectrum from each point on the sky corresponding to individual pixels in the array. The imaging spectrometer will therefore open a third dimension in astronomical observations by providing spectral information at each point in the object under study (e.g. galaxy, molecular cloud). While SCUBA-2 will provide unprecedented morphological information about such sources, composition and physical conditions can only be determined through imaging spectral measurements. The software requirements for this instrument will be presented in a separate document.

Introduction

In the simplest type of Fourier spectrometer, the Michelson interferometer (see Figure 1), the incoming beam of light (e.g. from the telescope) is divided into two beams of equal intensity by a beamsplitter. After reflection from a fixed and a moving mirror the beams recombine at the beamsplitter and are brought to a focus on the detector. The signal recorded by the detector as a function of the path difference, or delay, between the recombining beams is known as the interferogram (see Figure 2). The interferogram represents the autocovariance function of the incident radiation. Applying an inverse Fourier cosine transformation of the interferogram yields the spectrum of the source. Thus, while in principle the design of an FTS is quite simple, obtaining the spectrum requires sophisticated mathematical analysis.

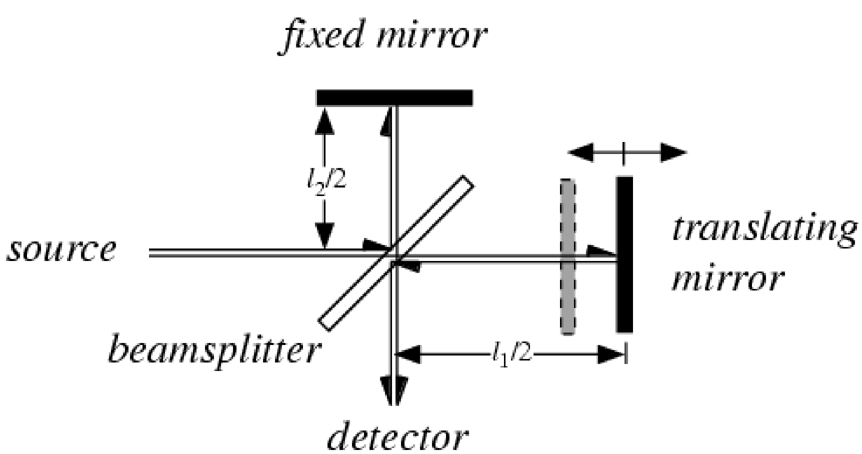

Figure 1. Typical Michelson interferometer. The optical path difference is l_1-l_2.

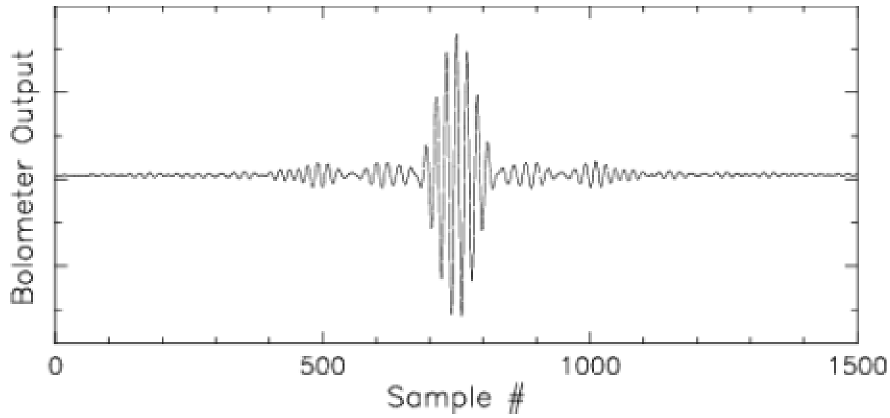

Figure 2. Typical Interferogram showing the Zero Path Difference (ZPD) feature.

The mechanical, optical, and software design of the SCUBA-2 FTS will be much more complicated than that of a standard non-imaging FTS. Also, since the FTS was not included in the initial design of SCUBA-2, the layout of the SCUBA-2 feed optics is not optimal for inclusion of an FTS.

Design Options

Possible design options for the spectrometer have been identified and discussed in the document: "SCUBA2_spectrometer_decision_sumary.doc". Please refer to this document for the details of this decision. The four options were:

1) A grating spectrometer
2) An Fabry-Perrot (FP) interferometer, cooled inside the SCUBA-2 cryostat
3) An external FP
4) A Fourier Transform Spectrometer

Options 1 to 3 were deemed impractical, and the FTS was chosen as the best solution.

Architecture of the FTS

The SCUBA-2 FTS will be based on the Mach-Zehnder design which has been adopted for the SPIRE instrument (of ESA's Herschel mission) and the U of L spectrometer operating at the JCMT. A schematic of a Mach-Zehnder FTS is shown in Figure 3. Radiation from the input ports passes through an equal intensity beam splitter, is reflected by stationary mirrors to a moving rooftop mirror, and then reflected to a second beam splitter. In the SCUBA-2 FTS, one input will be used for the astronomical source, the other input for a blackbody calibration source, and only one output port will be used.

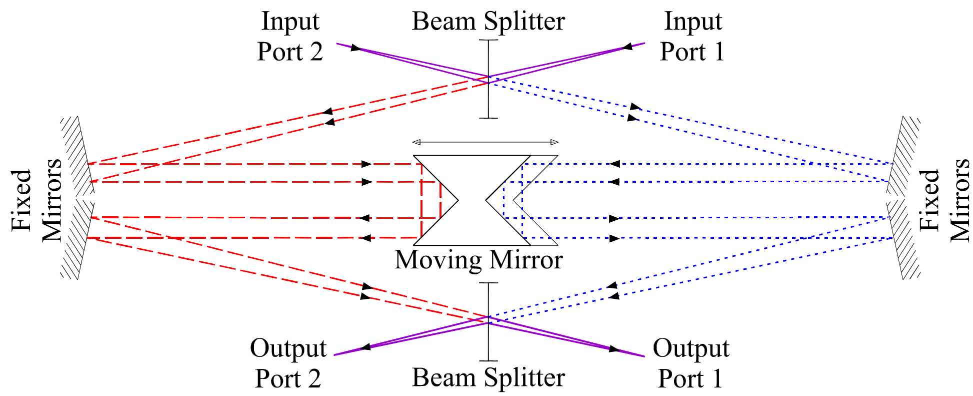

Figure 3. Schematic of a Mach-Zehnder FTS.

The design of the SCUBA-2 FTS is complicated by the fact that we do not have access to a small diameter collimated beam in the SCUBA-2 feed optics. In order to construct an imaging FTS for the SCUBA-2 system that uses at least one quarter of the full array in each band, the following key components are required:

1) Beam splitters: Two intensity beam splitters are required that have equal transmission and reflection in both the 450 and 850 bands. The target is to image one quarter of the full SCUBA-2 beam through the FTS, therefore the beam splitters will need to be large enough to accommodate one quarter of the full SCUBA-2 beam at the outside of the elevation bearing after it has been suitably collimated (~300 mm). Cardiff should be able to provide 300 mm beamsplitters, although none have yet been manufactured of this size. Manufacture of larger diameters may be possible with some retooling of the Cardiff shop.
2) Blackbody: A large aperture variable temperature cryogenic blackbody source will be required for calibration, reducing the power loading on the bolometers, and possibly for canceling out the large signal swings as the interferometer scans through the zero path difference (ZPD) position.
3) Pickoff mirrors: Since the beam is not collimated between mirrors C3 and N1, and there is not enough space to place an FTS directly in the beam, pickoff and return mirrors will be required to collimate the desired portion of the beam, pass it through the spectrometer, and return it to mirror N1 in its original state. These mirrors will need to be on a motorized stage so that they can be removed from the beam when the FTS is not in use.
4) Linear Stage: The moving rooftop mirrors will need to be large enough to accommodate the desired 300 mm beam, and will likely be quite massive. (If they are made from aluminum and not lightweighted, then the mass could be as large as 70 kg.) The linear stage must have a suitable load capacity, be powerful enough to accelerate the mirrors (~1 m/sec^2), and have a positional accuracy of 1 um or better. The required acceleration is not yet known, as possible FTS observing modes are still being investigated.

Figure 4 shows a potential mechanical layout of the FTS, mounted just outside the left Nasmyth elevation bearing. More images can be found on the U of L SCUBA-2 FTS webpages.

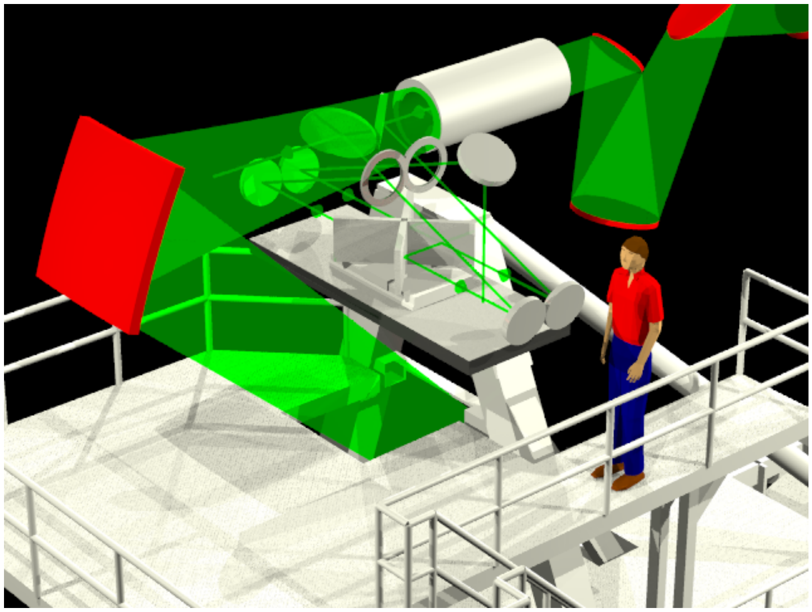

Figure 4. Conceptual model of the FTS mounting location. SCUBA-2 optics are shown in red.

Interfaces with SCUBA-2 and JCMT

Mechanical interface: The FTS will sit within the mounting framework for mirror N1, and will likely encroach on the receiver cabin access walkway. There should be adequate protection provided for the two fixed mirrors that will be nearest to the walkway so that they are not disturbed by passing traffic. Alternatively, the walkway may need to be extended. The entire FTS will be protected by a cover to prevent the accumulation of dust. The mass of the FTS is roughly estimated to be 600 kg, and the volume will be approximately 3 m x 1 m x 1.3 m. The JAC should prescribe limits for the inertial forces in all three axes that the FTS can exert on the mount during operation in order to prevent misalignment of mirror N1.

Operation of the FTS will consist of moving the pickoff mirrors into the SCUBA-2 beam, scanning the moving mirror assembly to acquire interferogram data, and then retracting the pickoff mirrors once FTS observations are complete.

Electronics. Construction of the FTS will require very little custom electronics; the major electronic component is the microcontroller based motion controller for the moving mirror linear stage and for the pickoff mirrors. The motion controller and electronics for the blackbody source will be interfaced to a control PC. This PC will be interfaced with the SCUBA-2 network so that the 32 bit stage position is recorded in the header of each frame when an FTS observation is in progress.

Software. The FTS control PC will take commands from the RTS Client to initiate a scan, and will send commands to the motion controller to move the mirror at the required speed and distance, and return the mirror position to the software pipeline. The control PC will also monitor the various limit switches and FTS housekeeping parameters.

The display provided to the observer by the FTS instrument control software should include the following information:

- Status of the instrument; i.e. position of the pickoff mirrors, position and velocity of the moving mirror, blackbody temperature, time remaining, etc.
- A real-time image of the array; i.e. from the standard SCUBA-2 quicklook display.
- A means to display the last interferogram from a given pixel, as well as the corresponding spectrum, for data quality assessment.

The rest of the information (source name, position in the sky, sidereal time, etc.) should all be given on the main SCUBA-2 display(s).

The FTS data processing will be performed within the SCUBA-2 data analysis pipeline. This FTS-specific code will be written by the U of L team, in close communication with the data analysis software group. An FTS software requirements document will describe these software issues.

Testability

a) In preparation for a normal shift:
Once the FTS pickoff mirrors have been moved into the beam, and the image quality verified, the FTS operation can be tested by performing a scan of the external SCUBA-2 flat-field source. If the moving mirror operates properly, then the resulting interferograms and spectra can be inspected to determine if the FTS performance is acceptable. The various housekeeping parameters monitored by the FTS control PC will indicate if there are problems with the instrument or the FTS blackbody.

b) As part of routine maintenance:
The FTS linear stage contains precision rails and bearings that will need to be lubricated periodically, and inspected for wear. On a yearly basis, or after any maintenance, the linear stage and optical alignment should be checked using a laser.

c) During development:
The FTS will be fully assembled and tested in the lab prior to commissioning, but there will be extra alignment tests required during installation at the JCMT. Image quality tests will have to be done on the overall SCUBA-2 optical alignment with the FTS in the beam.

Responsibilities

The U of L will acquire and/or produce all the mechanical and optical components required to build the FTS, as well as the FTS control PC. The optical and mechanical design will be done at the U of L. The optics, blackbody, linear stage, optical breadboard, and other components will be purchased from suitable vendors, but there will be many mechanical components and mounts that will be manufactured at the U of L.

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. Details will be described in the FTS software requirements document.

Dependencies

Information: Optical, mechanical, electronics and software interfaces (ATC, JAC, UBC)

Approval: JAC and ATC will provide final acceptance of the design.

Components: Beamsplitters will be manufactured by Cardiff. The optics will be custom machined by a suitable shop. Most other components are easily acquired from commercial sources.

Infrastructure: Lab space and time at U of L for initial construction and testing. Use will be made of U of L electronics fabrication equipment and personnel.

Funding: Provided by the CFI budget.

Risks

- Manufacture of large (>300 mm) diameter beamsplitters should be feasible, but has not yet been demonstrated.
- Mass of optics is a concern. Manufacture of light weight moving mirrors may add cost to the system. Force limits for N1 mirror framework need to be determined. This risk can be mitigated by reducing the acceleration of the linear stage.

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.