Commissioning of FTS-2, the SCUBA-2 Imaging Fourier Transform Spectrometer

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Abstract: We present early results from the commissioning of FTS-2, the imaging Fourier transform spectrometer for use with SCUBA-2 at the James Clerk Maxwell Telescope.
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1. Introduction

FTS-2 is an imaging Fourier transform spectrometer (FTS) operating as an ancillary instrument coupled with the SCUBA-2 submillimeter bolometer camera [1] at the James Clerk Maxwell Telescope (JCMT) in Hawaii. We have presented the design [2], construction and installation [3] of FTS-2 elsewhere; in this paper we present some of the very early results from the commissioning effort as the instrument is prepared for release to the astronomy community in August 2013.

Designed to fill a niche between the high spectral resolution but low pixel count JCMT facility instrument HARP-B [4] and the wider band but lower spectral and spatial resolution SPIRE FTS on the Herschel space observatory [5], FTS-2 provides moderate resolving powers of R ~ 10 to 5000 across the 450 and 850 µm atmospheric transmission windows over an instantaneous field of view (FOV) of ~5 arcmin^2. The science case for FTS-2 includes mapping the Spectral Energy Distribution (SED) of continuum emission in protostellar envelopes and molecular clouds at low spectral resolution, and probing the rich submillimeter spectrum of molecular lines in hot cores at higher resolution.

As the first imaging FTS to use superconducting transition edge sensors (TES) in the far-IR, FTS-2 will pave the way for future TES-based instruments such as the proposed SAFARI FTS on the SPICA space observatory [6,7,8]. Some of the idiosyncratic characteristics of SQUID multiplexed TES arrays, such as nonlinearity and flux jumping, require special attention when processing interferometric data, as will be shown below.

2. Commissioning Results

The first commissioning runs with FTS-2 took place in October and December 2012. Instrumental alignment and control software issues were addressed in October, and a limited number of on-sky spectral observations were performed in December in somewhat poor weather. These data are currently being analyzed to verify that the instrument performance matches theoretical predictions.

The FTS has internal ambient blackbody shutters that can be used to block either input port instead of operating in the normal dual-port mode [2]. Data collected in this mode represent the interferometric difference between the cold sky (in the 850 µm band) and the warmer shutter, and contain atmospheric ozone lines which can be used to calibrate the instrument resolution and frequency scale. The bandpasses of the SCUBA-2 filters can also be measured in this mode. While the poor observing conditions and nonlinearity issues make it challenging to extract accurate numbers for the bandpasses and resolution. The data are consistent with the design specifications with the maximum resolution being ~0.006 cm^{-1} at the array center and ~0.015 cm^{-1} at edge (~10 pixels or ~1 arcmin from axis).

Results from the preliminary analysis of commissioning data are shown in the figures. Figure 1 shows the obliquity effect, the shift in frequency for the off-axis pixels, which varies as expected. The left panel of Figure 2 presents a mosaic view of the spectra for one of eth SCUBA-2 arrays (4 are used). The right panel shows an interferogram from an axial pixel (top), the interferogram from a non-linear pixel (middle, zoomed), and the effects of flux jumping in the squid readout electronics (bottom).

The impact of the nonlinear response of the TES under a large differential loading (one port viewing the ambient shutter, the other the cold sky) is shown in Figure 3. The harmonics, whose amplitude and phase change sign, as expected, are clearly evident and prevent robust phase correction. In normal operation the two ports view the sky and this non-linearity should not be observed.

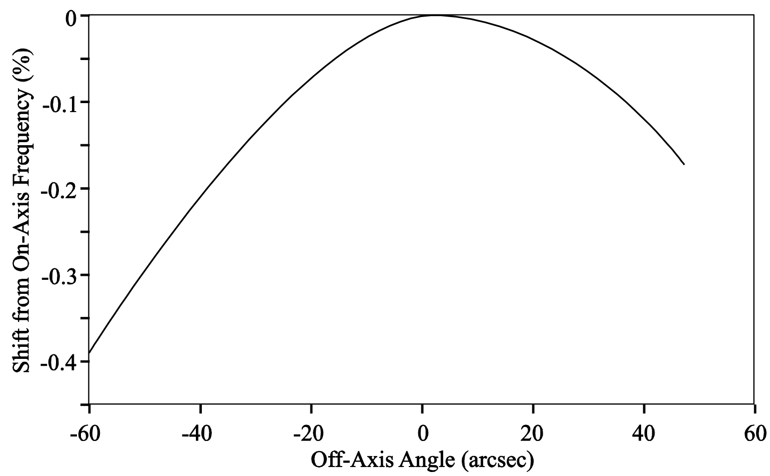

Fig. 1. Apparent spectral line frequency shift as a function of off-axis angle, calculated from fits to atmospheric ozone line centers. Obliquity effects within the interferometer produce an apparent contraction of the frequency scale for off-axis rays which have a longer effective optical path. The shift corresponds to ~7 resolution elements at the periphery of the FOV, but is easily corrected once characterized.

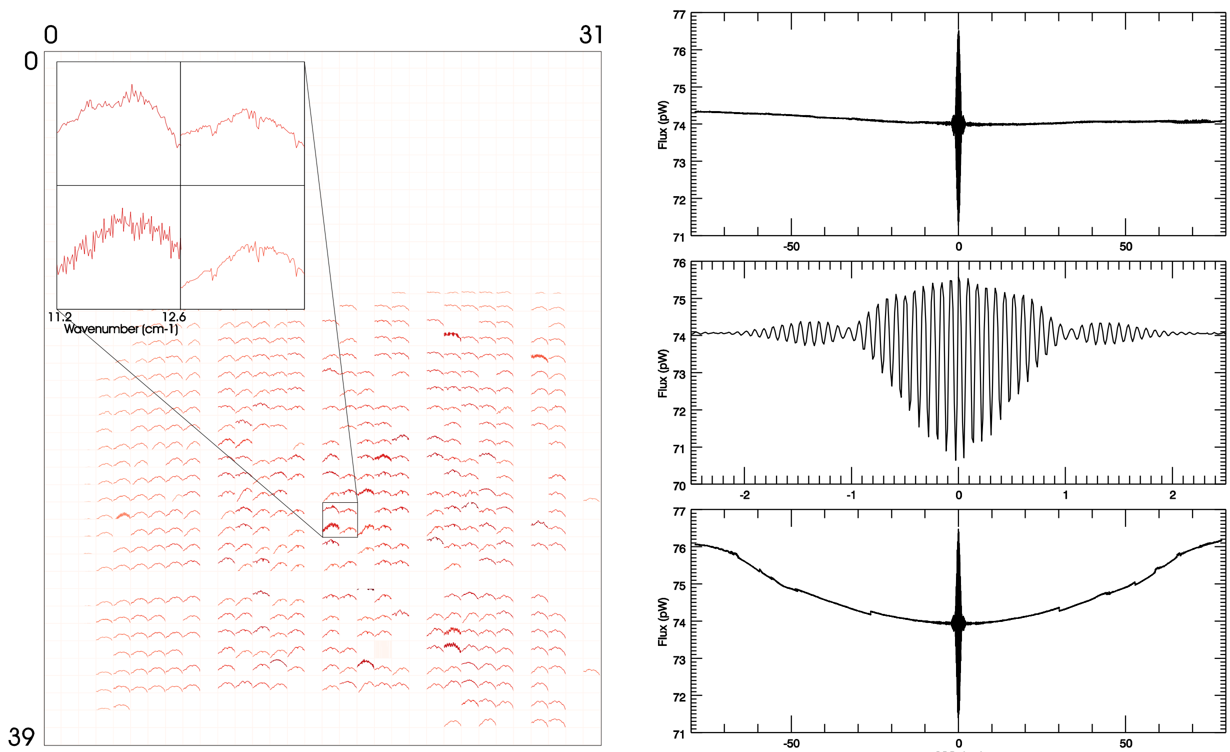

Fig. 2. Left: Composite image showing the raw spectra from ~480 bolometers in the SCUBA-2 s8c detector sub-array that receive the signal from one output port of the FTS. Dead pixels, rows and columns can be seen in the 32x40 sub-array. Inset shows sections of 4 typical raw spectra of atmospheric emission and ozone lines, from the center of the FOV; various artifacts are evident due to nonlinearity of the detector response and discontinuities in the interferogram signal. Right Top: A high resolution interferogram from a well behaved bolometer near the optical axis. Right Middle: Central region of an interferogram from a nonlinear bolometer. Right Bottom: Interferogram from a pixel away from the optical axis exhibiting baseline curvature due to vignetting and beam shearing in the interferometer, as well as discontinuities in the signal due to flux jumps in the SQUID readout electronics.

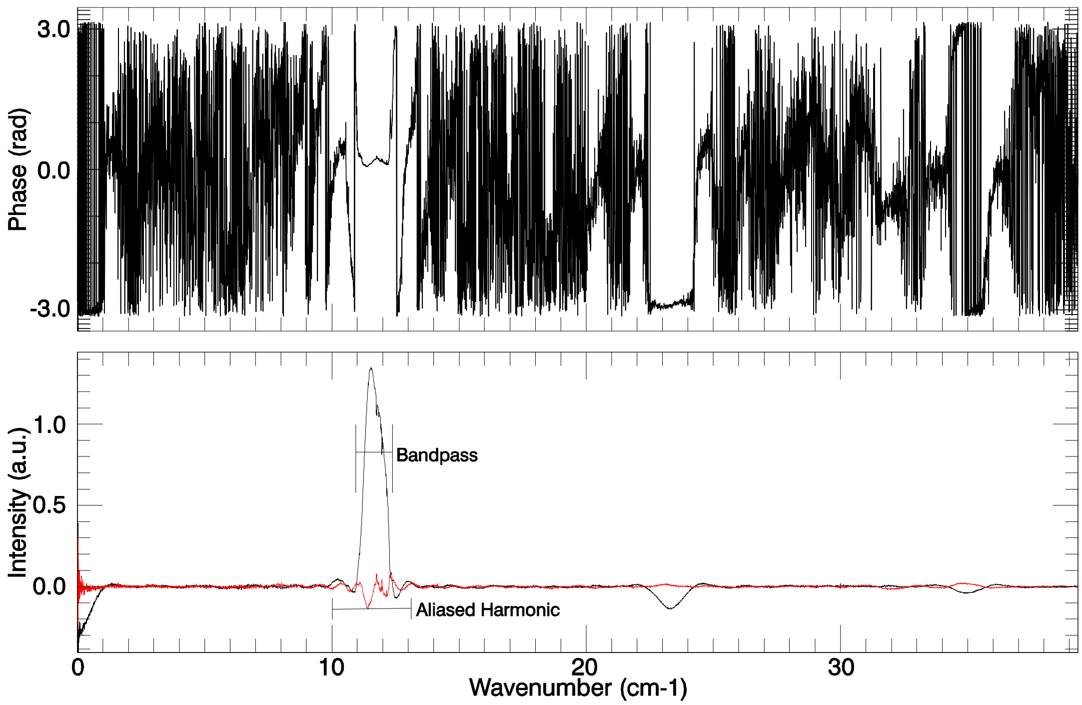

Fig. 3. Bottom: Real and imaginary phase-corrected spectra for the FTS viewing the atmosphere with one blackbody shutter closed. Nonlinearity is evidenced by the harmonics of the filter bandpass. Top: Phase spectrum for the same observation showing the relatively flat phase within the bandpass, but also the effects of the phase in the harmonics. The presence of this additional nonlinear harmonic phase component introduces a flip of π near the edges of the bandpass, which complicates phase correction.

3. Next steps

Commissioning of FTS-2 continues in March. Since the interferogram and OPD signals are measured on different time grids interpolation is required. We will study the scan speed\interpolation issue to determine the optimal speed of the moving mirror. The two remaining issues are to determine the resolution as a function of the field of view, and the sensitivity. While the current data are of poor quality, ozone lines are evident in the spectra and, being an order of magnitude narrow than our resolution can be used for this purpose. The sensitivity of FTS-2 requires stable atmospheric conditions with low precipitable water vapor. The first shared risk science run with FTS-2 is in May. Results from the next commissioning phase and the first science run will be presented.

4. References

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