Beamsplitter Emission in the Herschel/SPIRE Fourier Transform Spectrometer

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Abstract: Performance studies of the Herschel/SPIRE FTS show a significant contribution to the measured interferogram from beamsplitter emission when both input ports are well balanced. We describe results from further exploration of this effect.

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1. Introduction

The SPIRE instrument on-board the Herschel Space Observatory contains an imaging Fourier transform spectrometer (FTS) in a Mach-Zehnder (MZ) configuration[1]. For broad-band/continuum observations, the challenging dynamic range requirements of an FTS interferogram signal near zero optical path difference (ZPD) can be reduced by port balancing. In the case of SPIRE this is accomplished by placing a calibration source (SCAL) at the second input port of the FTS (port B), in order to compensate for the blackbody emission from the 3.5 m passively cooled telescope observed through the primary input port (port A). The technique of port balancing is particularly advantageous in cases where blackbody emission from the input optics of an instrument produce a radiative background which dominates a much weaker source signal, a case frequently found in far-infrared and submillimetre astronomy. During performance testing of the SPIRE FTS we have shown that beamsplitter emission may contribute significantly to the measured interferogram when port balancing is optimal[2]. This work describes an in-depth study of the effects of beamsplitter emission in FTS spectra.

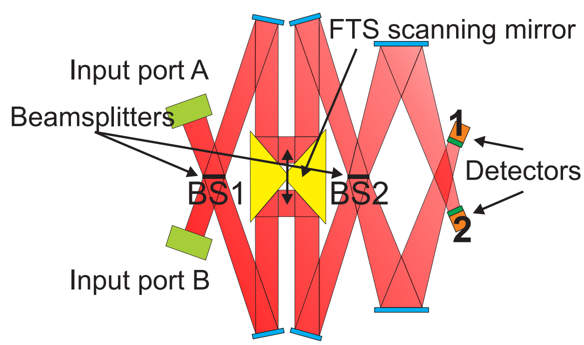

Fig. 1. Diagram of the Herschel/SPIRE Fourier transform spectrometer.

2. Theory

The SPIRE FTS (Fig. 1) contains two identical beamsplitters (BS1 and BS2); each of which is characterized by complex reflection and transmission coefficients, $re^{i\rho}$ and $te^{i\tau}$. The reflectance and transmittance are given by $R = r^2$ and $T = t^2$ respectively, and the phase difference between reflection and transmission terms is given by $\phi = \rho - \tau$, which is $\pi/2$ in the case of a non-absorbing beamsplitter. In practice, beamsplitters exhibit small but finite absorption and thus act as sources of emission. Although radiative emission from both beamsplitters contributes to the total flux received at either FTS output, only the emission from the first beamsplitter may contribute to the modulated interferogram signal[3]. For spectra $E_A(\sigma)$ in input port A, $E_B(\sigma)$ in input port B, $E_{\mathrm{BS1}}(\sigma)$ from BS1, and σ representing the frequency in cm^{-1}, the modulated interferogram observed at either output port 1 or 2 can be expressed as:

$$\begin{aligned} I_{\frac{1}{2}}(z) \;=\; & \int 2RTE^2_{\frac{A}{B}}(\sigma)\cos(2\pi\sigma z)d\sigma + \int 2RTE^2_{\frac{B}{A}}(\sigma)\cos(2\pi\sigma z \mp 2\phi)d\sigma \\ & + \int 2\sqrt{RT}E^2_{\mathrm{BS1}}(\sigma)\cos(2\pi\sigma z \mp \phi)d\sigma \end{aligned} \quad . \qquad (1)$$

For a well balanced interferometer the first two terms in Eq. 1 complement each other due to the fact that $\phi \approx \pi/2$. In this case the E_{BS1} term is the dominant contribution towards the modulated signal. The 2ϕ term is analogous to the Hamy Phase Parameter (HPP)[4] which is equal to π in the absence of absorption. In optical media with low absorption, 2ϕ may occupy a range of values near π that satisfies $|\cos\phi| \leq A/(2\sqrt{RT})$[5]. Any absorption in the beamsplitter results in deviation of ϕ from $\pi/2$ and a non-zero beamsplitter emission component (E_{BS1}). The phase shift of $\pi/2$ in the third term of Eq. 1 is equivalent to a sine term having odd symmetry. If the contributions of this term are not subtracted from the interferogram prior to phase correction and Fourier transformation, the derived spectra will contain amplitude and phase errors.

3. Results

To illustrate the effect of beamsplitter emission, Fig. 2.a shows a short region of a SPIRE interferogram taken near ZPD with one input port dominant (solid line). Also shown in Fig. 2.a is the residual interferogram that arises from E_{BS1} under the conditions of optimal nulling (to the same scale - dotted line, normalized - long dashed line), clearly illustrating the odd symmetry of this component.

To further study the nature of the interferogram component due to beamsplitter emission, we modified an existing laboratory MZ FTS, of design similar to SPIRE, so that the beamsplitter (BS1) could be heated above ambient temperature while identical sources were placed at the two input ports. Highly-oversampled low-resolution interferograms were taken in rapid succession while the beamsplitter cooled. The top and bottom traces in Fig. 2.b represent the cases where one of the input ports is dominant and the expected even symmetry is observed. The middle two curves represent the case where the input ports are balanced and the beamsplitter emission is observed at two temperatures; the odd symmetry (i.e. shift of $\pi/2$) is clearly evident. The low thermal mass of the beamsplitter together with the coupling of the embedded

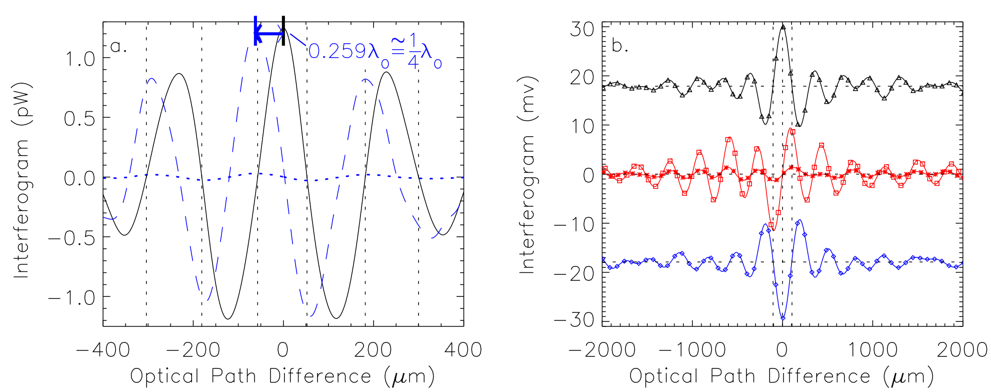

Fig. 2. a. SPIRE interferograms demonstrating beamsplitter emission. b. Room temperature FTS observations illustrating increased emission as BS1 is heated.

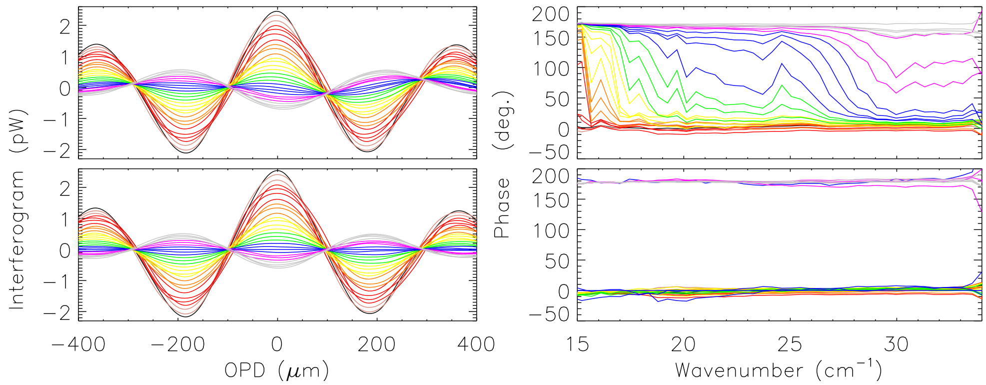

Fig. 3. Removal of the beamsplitter emission component of SPIRE Interferograms.

metal grids to the large beamsplitter frame allows the beamsplitter to reach thermal equilibrium quickly. The contribution from the beamsplitter emission to the total interferogram may thus be considered to be a constant component which must be removed prior to phase correction and Fourier analysis.

Figure 3 illustrates the improvement in the spectral phase across the $15 - 33.5$ cm^{-1} band that results when the beamsplitter emission component is removed from the interferogram. The upper plots show the raw interferograms and subsequent spectral phase when the beamsplitter emission term is present. The lower plots show the interferograms when the beamsplitter emission term has been subtracted and the resulting spectral phase which is centered on zero or π as expected.

4. Conclusions

Results from a study of the effect of beamsplitter emission on port-balanced FTS interferograms have been presented. This effect has been observed in an FTS operating under vacuum at cryogenic temperatures and in one operating at room temperature where we have controlled the temperature of the beamsplitters and input sources directly. While the presence of beamsplitter emission in the SPIRE instrument was only detected during the testing of the flight-model, it is in fact unavoidable at these long wavelengths. It is a testament to the sensitivity of the SPIRE detectors that the contribution to the interferogram shown in Figure 3, which arises from a beamsplitter of temperature less than 10 K, can be observed easily. However, since this effect is systematic, once determined, it can be readily removed from the raw data. In light of these developments, a specific module has been added to the SPIRE data processing pipeline to account for beamsplitter emission. We look forward to verification of this effect during the commissioning phase of the SPIRE instrument following the launch of Herschel scheduled for April of 2009. This research has been funded by AI, CSA, NSERC, and STFC.

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