Infrared Spectrograph
Technical Report Series

IRS-TR 04005: Using Orthogonal Slits to Investigate Spectral Discontinuities

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Abstract

This report shows that the orthogonality of the Short-Low (SL) and Long-Low (LL) slits in the IRS allows the position along one slit to be used to estimate the position across the other. In addition, the dependence of flux in SL order 1 is consistent with spectral pointing-induced throughput error (SPITE), making it possible to apply a correction to the spectra which will reduce the discontinuities between spectral segments. On average, the telescope systematically places a source $\sim 0.''4$ to one side of the central axis of the SL slit, which exacerbates the effect of SPITE in SL. There may be a dependence of flux in LL order 2 with position along the LL slit, but this dependence is not strong and it would not arise from SPITE.

1 Introduction

The flux discontinuities between spectral segments in the Infrared Spectrograph (IRS) have been an on-going issue. In the calibration data, the discontinuities between Short-Low (SL) and Long-Low (LL) can be as large as 40% or more, although on average they are more typically just a few percent (Sloan 2004, IRS-TR 04002). Problems with how early versions of the data reduction pipeline fit

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slopes to signal ramps may be responsible for the larger discontinuities (Sloan et al. 2004, IRS-TR 04004), but the leading suspect for smaller discontinuities remains Spectral Pointing-Induced Throughput Errors (SPITE, see Sloan et al. 2003, IRS-TR 03001 and Nerenberg & Sloan 2003, IRS-TR 03003).

SPITE results from the fact that the spectroscopic slits are small enough to block the passage of some of the light from a point source. The throughput depends on both position of the source within the slit and wavelength. The spectroscopic calibration corrects for the loss of radiation for a source centered in the slit, but random pointing errors will move the source being calibrated from the center of the slit, and this offset typically produces an apparent loss of flux which can be several percent in the SL slits. Correcting for the effect of SPITE on otherwise fully calibrated spectra remains an outstanding issue.

The focal plane coordinates for each IRS module are defined so that the v and w axes run perpendicular and parallel to the long axis of the slit, respectively (i.e. in the dispersion and cross-dispersion directions). As described in IRS-TR 03003, the SPITE correction should be a simple function of position of the target in the cross-dispersion direction (v) in the spectroscopic slit. The position of a source along the w direction in any aperture is directly measurable from the position of the spectrum on the detector array, but motion in the v direction will only change the relative strength and shape of a spectrum, which we would like to correct for.

Unfortunately, a direct means of measuring the Δv offset from the central axis of the slit does not exist. A typical pointing error will be less than one arcsecond, but at this stage of the mission the reconstructed pointing determined by the Spitzer Science Center (SSC) and supplied to users in the header of all FITS images is not known to that accuracy (Keremedjiev & Sloan 2004, IRS-TR 04007 confirm this limitation).

This report shows that the geometry of the SL and LL slits can be exploited to determine the position of a source in the v direction, which allows a correction for SPITE.

2 Analysis and Discussion

3 Determining the position of a source in the slit

In a typical staring observation, the telescope will move a source to SL order 2 (SL2), then to SL1, then Short-High, LL2, LL1, and finally Long-High. In each of these six apertures, the telescope places the source in two nod positions.

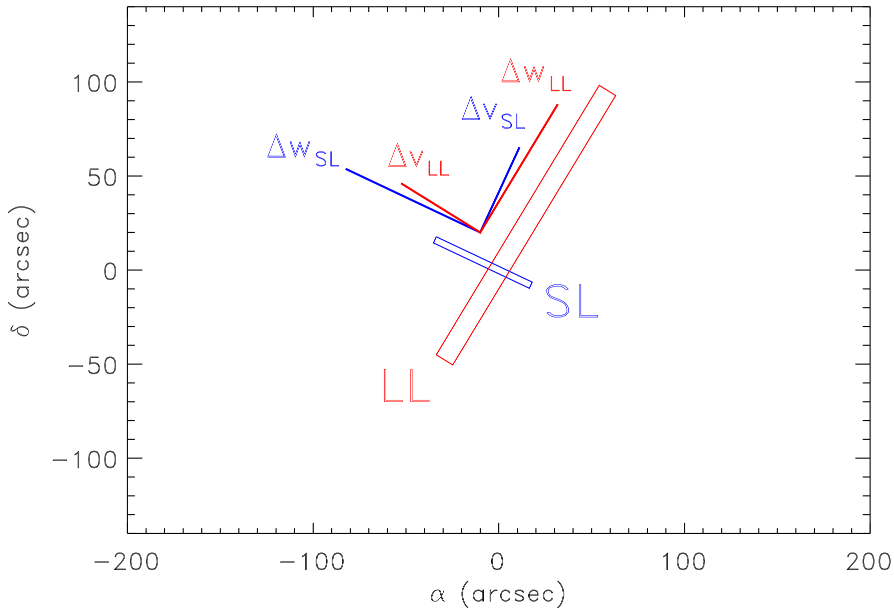

Figure 1 —The SL and LL slits and their coordinate systems, for an arbitrary spacecraft orientation. The SL coordinates are in blue and the LL coordinates are in red.

Each move of the telescope introduces a small offset error, and these errors will accumulate during an observation. As long as these additional errors are small, the initial pointing error to SL will dominate.

Figure 1 illustrates the design of the IRS, which places the SL and LL slits approximately perpendicular to each other. If the offset errors accumulated from SL to LL are small, then the initial offset of a source in SL coordinates (Δv_{SL}, Δw_{SL}) and the final offset of a source in LL coordinates (Δv_{LL}, Δw_{LL}) are related by a simple rotation of ~ 90 deg. While we cannot measure Δv directly in either slit, we can estimate it by using Δw from the other slit. To state the method explicitly, Δw_{LL} might serve as a proxy for Δv_{SL}, and Δw_{SL} might serve as a proxy for Δv_{LL}, provided the accumulated errors from each move of the telescope are small in comparison.

The repeated observations of the K4 giant HD 173511 (20 independent observations from Campaign P through 4) and the A1 dwarf δ UMi (A1 Vn, 25 observations in the same period) serve as the primary data set for the following analysis. Sloan (2004, IRS-TR 04002) describes the method used to process and calibrate the spectra.

To determine the position of the star along the SL and LL slits (w), a Gaussian was fit to the spectral image in a region centered on row 64. The Gaussian centroid in pixel coordinates is scaled to an offset in arcseconds using the pixel scales of $1\overset{\prime\prime}{.}8$/pixel for SL and $4\overset{\prime\prime}{.}8$/pixel for LL. Assuming that the individual pointings to each nod position in each slit are randomly distributed about the nominal nod position means that the centroid of each distribution would correspond to an offset of zero. To minimize the impact of accumulated offset errors as the telescope moves from SL to SH to LL, this analysis will use measurements from the last SL observation (SL1 Nod 2) and the first LL observation (LL2 Nod 1).

3.1 Determining throughput from the ends of the spectra

Figures 2 and 3 plot throughput as a function of position for HD 173511 and δ UMi, respectively. The method used to measure throughput in these figures is the same as that used in IRS-TR 04002, namely averaging the flux from 14.0 to 14.3 μm in either the SL or the LL spectrum.

In Figure 2a, Δw_{LL} serves as a proxy for Δv_{SL}, and the throughput is clearly dropping as one moves the star to negative offsets. Figure 3a shows the same effect, showing that the random accumulated offset errors from SL1 to LL2 are small compared to the initial offset error. Otherwise, no dependence of throughput on source position along the LL slit would be apparent.

In these figures, the mean offset determines the zero position, which would be consistent with random pointing errors, but Figures 2a and 3a show an asymmetric dependence of flux with offset. As the offsets become negative, the throughput quickly drops, but the throughput stays roughly constant with positive offset. One data point in Figure 2a suggests that the throughput might drop with large positive offset, but as shown in §2.2 below, a modified analysis shows otherwise. Figures 2a and 3a suggest that there is a systematic pointing error in Δv_{SL}. These data are fully consistent with what is expected from SPITE if the mean pointing to SL1 is offset slightly from the center of the slit.

This offset can be ruoghly estimated by determining the offset necessary to produce the observed loss of flux at 14.0–14.3 μm. For HD 173511, the average flux for offsets from $0.\!''0$ to $0\overset{\prime\prime}{.}3$ is 0.631 Jy, and this is assumed to be the maximum throughput. The isolated flux at $-0.\!''32$ is 0.570 Jy, giving a ratio to the maximum throughput of 0.903. This throughput ratio corresponds to an offset from the actual center of the slit of $0\overset{\prime\prime}{.}85$, and this applies to the data point $0\overset{\prime\prime}{.}32$ from the centroid of the distribution of pointings to SL1. Therefore, the centroid of the pointing distribution in SL1 is located at $v_{SL} = -0\overset{\prime\prime}{.}53$. A similar analysis

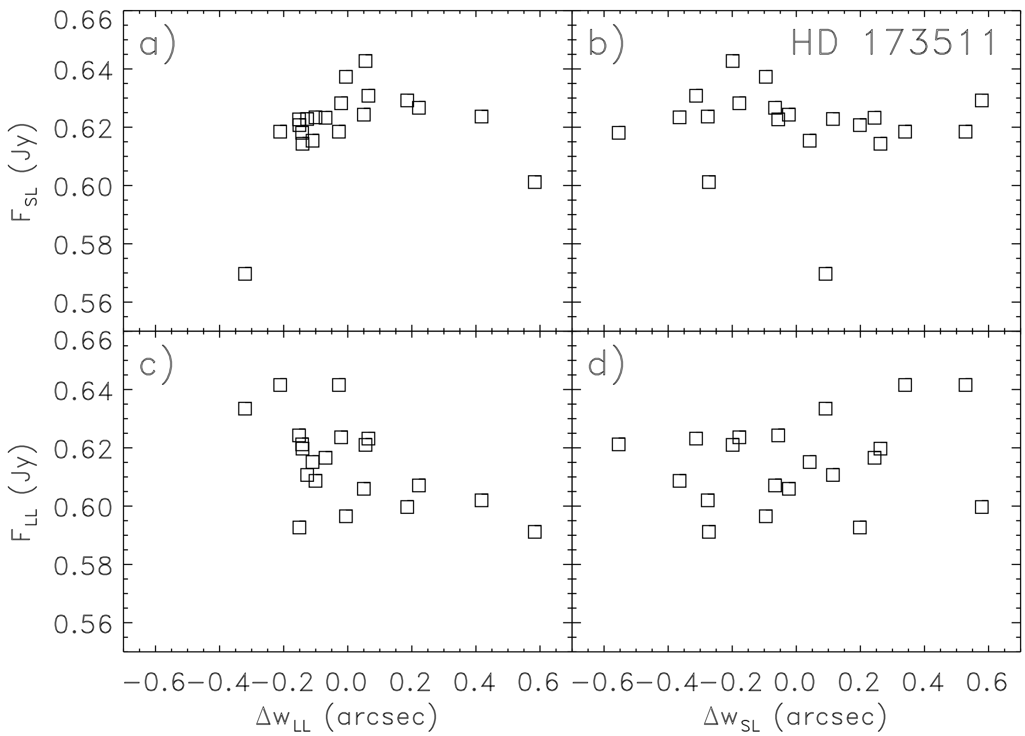

Figure 2 —The dependence of apparent flux on position in the spectroscopic slit for HD 173511. For both SL1 and LL2, the flux is an average from 14.0 to 14.3 μm. Panel (a) shows how the flux in SL1 changes with position across the SL1 slit (using Δw_{LL} as a proxy for Δv_{SL}). One slit edge is apparent (in the negative direction), and on average, the pointings are not centered in the slit. Panel (b) shows no noticeable dependence on throughput in SL1 with position along the slit (Δw_{SL}). Panel (c) shows that as the source moves along the LL2 slit (Δw_{LL}), the average flux changes, although the spread at a given position is large. Panel (d) shows no apparent relationship between flux in LL2 and position across the slit (using Δw_{SL} as a proxy for Δv_{LL}.

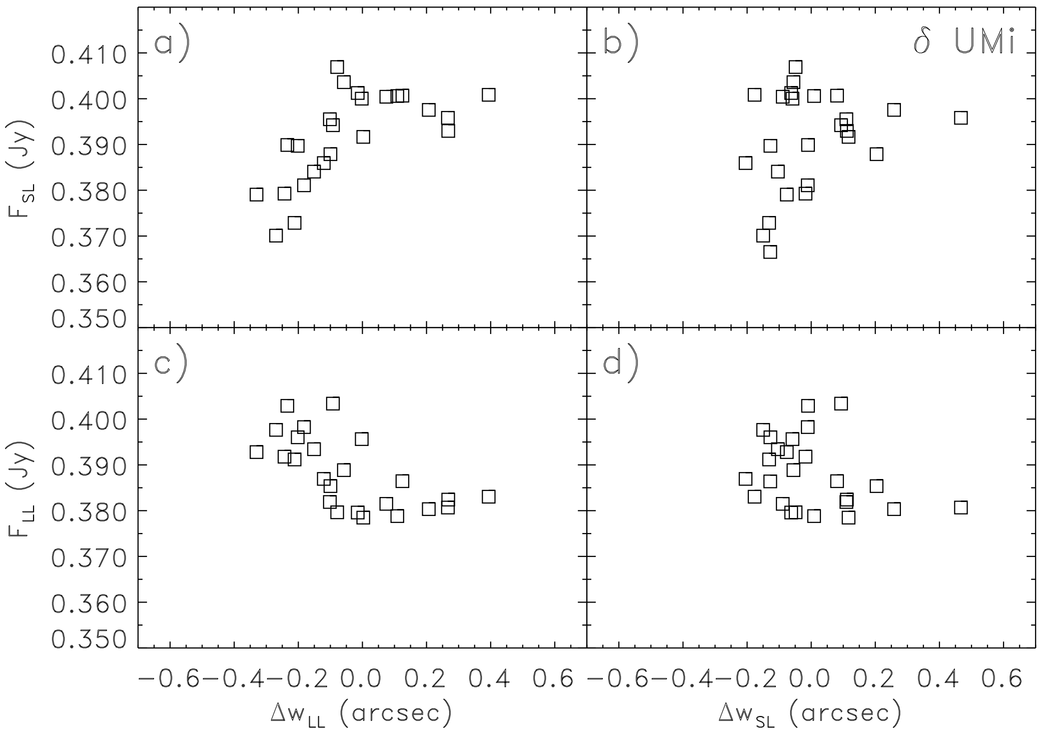

Figure 3 —As Fig. 2, but for δ UMi. Both figures show similar results.

for δ UMi using the three pointings with $\Delta w_{LL} < -0\farcs24$ puts the centroid of the pointing distribution at $v_{SL} = -0\farcs35$. Combining these resuls gives an estimate for the systematic pointing error in SL as $-0\farcs44 \pm 0\farcs13$.

While this systematic offset error is only a rough estimate, it should be clear that Spitzer is suffering from a systematic pointing offset in SL. Given that SL is the narrowest slit and thus must prone to problems from SPITE, this error should be corrected.

Figures 2c and 3c plot the throughput in LL as a function of position along that slit (Δw_{LL}). While both figures show a large scatter for offsets near zero, the spectra with the largest negative offsets along the slit tend to have the most flux, while the spectra with the largest positive offsets tend to have the least flux. Thus, as one moves from negative to positive offset *along* the LL slit, the apparent flux in LL *decreases*, and because this motion is analogous to motion *across* the SL slit and we begin with the source already on the negative side of the slit, the apparent flux in SL *increases*. These diverging behaviors for the same motion explain the anti-correlation of the flux in SL and LL illustrated in Figures 4 and 5 in IRS-TR 04002.

The apparent dependence of flux in LL2 as a function of position *along* the LL slit is troubling, as this cannot be caused by SPITE. It is not clear what would cause such an effect.

Panels b and d in Figures 2 and 3 show no discernable dependence of flux in either slit with the Δw_{SL} coordinate, i.e. with motion along SL or across LL. One would not expect to see a dependence of apparent flux in SL with position along the SL slit. In Panel d, Δw_{SL} serves as a proxy for Δv_{LL}. No loss of flux with position across the LL slit is apparent because the total range of offsets, $1\farcs2$, corresponds to only about 1/8th the width of the slit.

3.2 Determining throughput from the spectral images

It is possible that measuring the throughput using a small wavelength region in the spectra may introduce artifacts into the data, so it would be wise to check the results by summing the flux directly in the spectral images.

Figures 4 and 5 present the flux in the spectral images (using the *bcd fp.fits files* as a function of position of the source in the slit. For SL, the sum covers all pixels in the first order exposed to the wavelength range 9.0–13.0 μm. For LL, the wavelength range is 15.0–20.0μm. The most important result, that we can see one edge of the SL slit, remains unchanged. In the HD 173511 data, the one data point suggesting the other edge might be visible has moved closer to the maximum

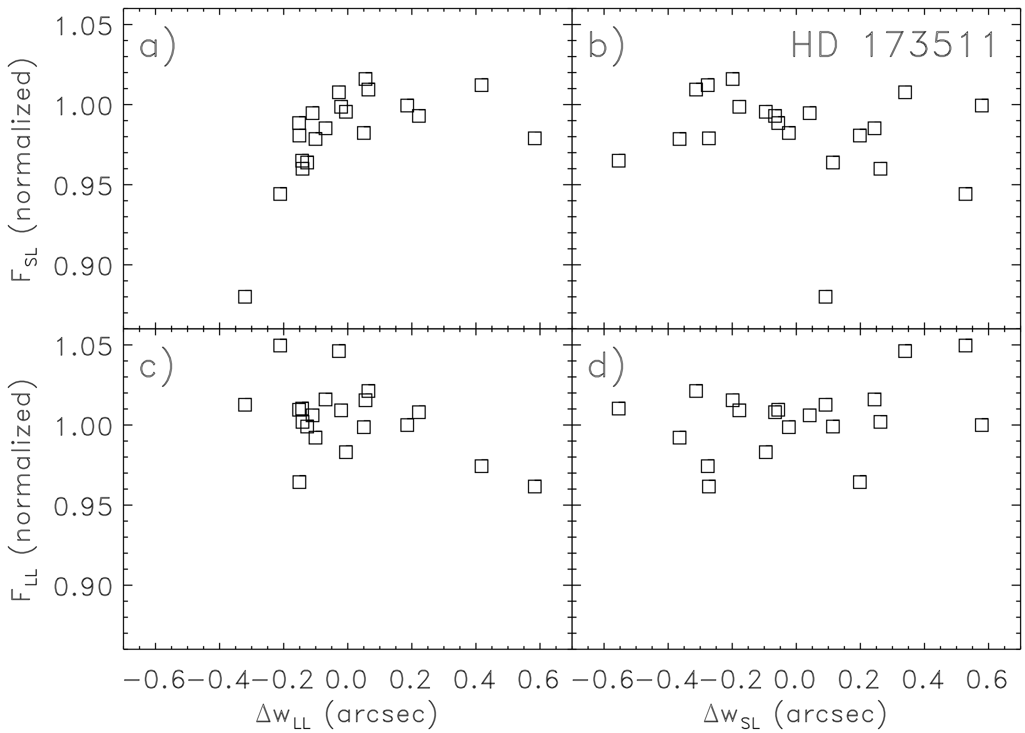

Figure 4 —As Fig. 2, but for flux summed from the spectral images. This figure confirms the results seen in Fig. 2, except that only one edge of the SL slit is apparent now in Panel a.

throughput. The dependence of flux with position in LL2 is still apparent in the HD 173511 data, but less so in the δ UMi data. As before, the plots of flux vs. Δw_{SL} resemble scatter plots.

4 Conclusion

This experiment demonstrates the utility of using the apparent position of a source along the long axis of the LL slit (Δw_{LL}) as a proxy for position across the SL slit (Δv_{SL}), and vice versa. Since SPITE depends mostly on position across a slit, this result provides a means of making a SPITE correction.

Further, the effects of SPITE are readily apparent in SL1, and for both objects considered here, one edge of the slit can be clearly seen, which suggests that that the telescope is systematically pointing to a position to one side of the central axis of the slit. The analysis allows only a rough estimate of this systematic pointing error; it is $-0.''44 \pm 0.''13$. Because SL is the narrowest slit, it is most sensitive to

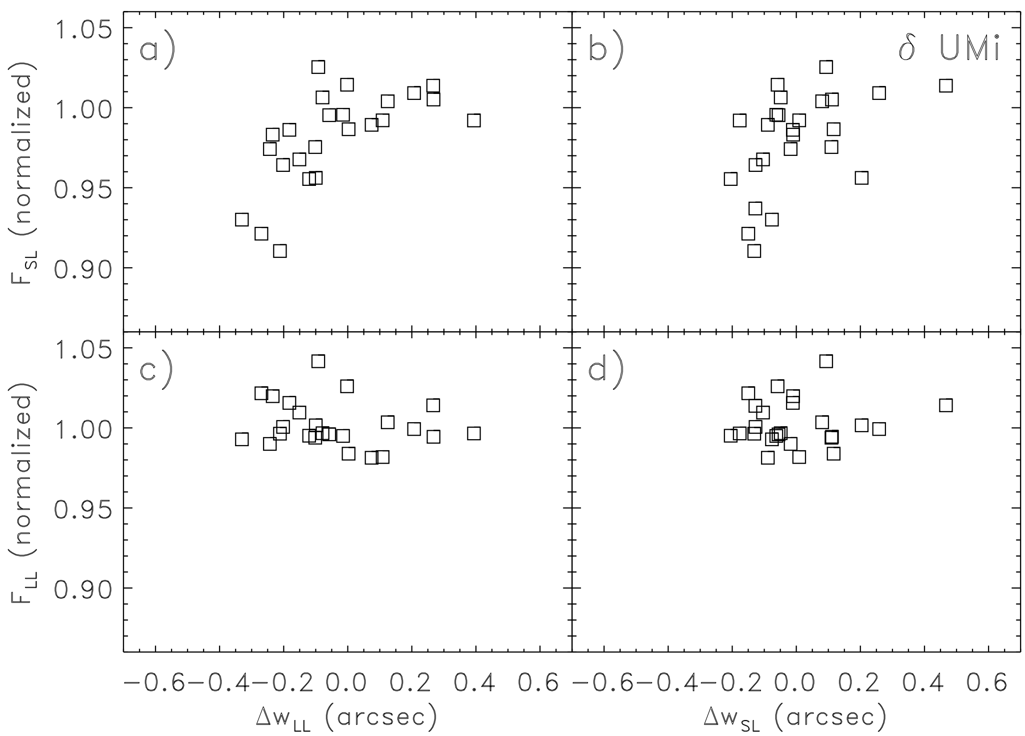

Figure 5 —As Fig. 4, but for δ UMi.

effects from SPITE, which only increases the significance of any systematic offset errors in this module.

There may also be a dependence of apparent flux in LL2 with position *along* the LL slit. SPITE could not produce this effect; what could is not clear.

For typical offset errors, SPITE produces errors in the SL spectrum up to 10%. Thus, correcting for SPITE effects in SL will help reduce the discontinuities in the spectra. The behavior in LL must have a different cause, thus a SPITE correction cannot remove all discontinuities from the spectra.

References

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