**Infrared Spectrograph**
**Technical Report Series**

# IRS-TR 06001: Correcting Spectral Pointing-Induced Throughput Error in Short-Low Order 1

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**Abstract**

Previous observations and analysis have shown that Spectral Pointing-Induced Throughput Error (SPITE) can have a measurable impact on the shape and continuity of spectra from the Infrared Spectrometer. We demonstrate here that for the majority of pointings to the Short-Low module, a simple scalar correction will eliminate most of the effects of SPITE. The Short-Low and Long-Low slits are nearly perpendicular, allowing an estimate of position across one slit by measuring position along the other. This report also shows that using these positions to determine a scalar correction in Short-Low Order 1 provides a good correction in most cases.

## 1 Introduction

During the course of the *Spitzer Space Telescope* mission thus far, Spectral Pointing-Induced Throughput Error (SPITE) has been shown to be a significant problem both theoretically and experimentally. Sloan et al. (2003) modeled the possible effects of SPITE and concluded that it would affect both the overall shape of a

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spectrum and the continuity between spectral segments observed in different apertures. Sloan et al. (2004b) confirmed this theoretical result experimentally using data from the first “Double-star Experiment”, which is described below, in §2.1.

The Short-Low (SL) and Long-Low (LL) slits are nearly orthogonal to one another. If a star is observed in both slits, the position of the star *along* one of the slits can be used to estiamte its position *across* the other, as shown by Sloan (2004a).

We concentrate on SL1, which is most susceptible to SPITE due to its small size, both with respect to likely pointing errors and the size of the point spread function (PSF). This report has two objectives. First, we show that the correction needed for SPITE can be a simple multiplicative factor as long as pointing error is not too large. Second, we develop an algorithm to use the position of the star in LL to estimate the needed SPITE correction and demonstrate that this algorithm works.

# 2 Method

## 2.1 The Double-star Experiment

The Double-star Experiment, described in detail in Sloan et al. (2004b) provided the information used to generate the scalar SPITE correction in this technical report. This experiment observed two sources separated so that one was on the blue peak-up (PU) sub-array while the other was in the slit for Short-Low Order 1 (SL1). The primary target was stepped in the dispersion direction of SL1 (i.e. across the slit) in $0\farcs2$ increments. The secondary target remained in the red PU field, allowing us to accurately measure its position in the focal plane and determine the corresponding position of the primary target in the SL1 slit.

While the position along the slit ($w$ coordinate) can be easily determined by looking at the location of the primary target within the slit, the secondary target provides the only direct means of assessing the position across the slit ($v$ coordinate).

## 2.2 Determining a scalar SPITE correction

We determined the throughput by averaging the strength of the extracted and calibrated spectrum from 8.8 to 14.0 $\mu$m.[1]. As described by Sloan et al. (2004b),

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[1] The average was performed in $\lambda^2 F_\nu$ units to weight data at all wavelengths equally.

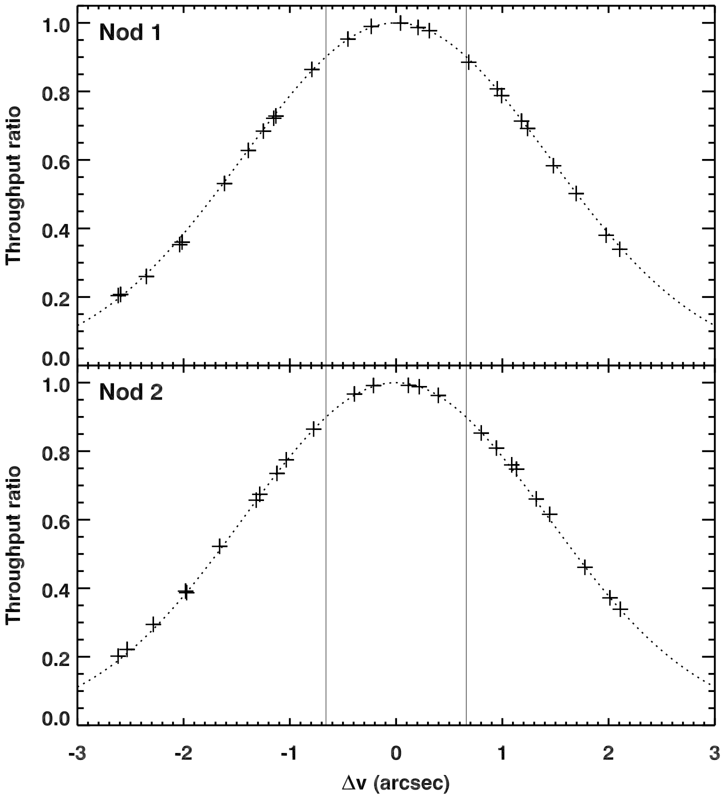

Figure 1 —The throughput in both nod positions as a function of position across the slit ($\Delta v$). The throughput has been normalized to one at the center of the slit. The dotted lines show the Gaussians defined in Equations (1) and (2). The vertical lines mark where the throughput is 90% of the maximum, at $\Delta v = \pm 0\farcs66$.

there was a systematic difference of $0\farcs27$ between requested and actual $\Delta v$ in SL1 when the Double-star Experiment was run (IRS Campaign 7, 2004 May).

Figure 1 presents the throughput in the SL1 as a function of offset across the slit for both nod positions. We have defined the center of the slit to be the position of maximum throughput and normalized the data to be unity at that position. Below, we refer to this normalized throughput as the throughput ratio. The dotted lines in the figure show Gaussians fit to the throughput ratio, as given by the equations below:

$$T_1 = e^{-(\Delta v/1.433)^2/2}, \tag{1}$$

$$T_2 = e^{-(\Delta\nu/1.447)^2/2}, \tag{2}$$

where $\Delta\nu$ is in arcseconds.

If the $\Delta\nu$ offset is known, then these functions provide a simple means of calculating the throughput ratio. Dividing the entire SL1 spectrum by this quantity will correct the spectrum for SPITE.

## 2.3 Pointing error

From IRS Campaign P in the Science Verification phase through IRS Campaign 29, we have observed the standard star HD 173511 80 times. These observations provide a good means of assessing the accuracy of pointings to the center of the IRS slits. We are interested in $\Delta\nu$, the offsets in the dispersion direction, in SL1. Sloan (2004a) described how the orthogonality of the SL and LL slits allows us to estimate the $\Delta\nu$ offset in SL1 by measuring the $\Delta w$ offset in LL2. In all observations, SL completes with SL1, and LL begins with LL2.

We determined the position of each spectrum in $\Delta w$ for LL2 by fitting a Gaussian across the spectrum in the five central rows and taking the mean of these Gaussians to be the pointing. For each nod, we took the centroid of all 80 pointings to HD 173511 to be the nominal zero point, then combined the two nod distributions into one.

Figure 2 presents the resulting pointing distribution for HD 173511 along the LL2 slit, which, as we have said, is a proxy for the pointing across the SL1 slit. Fitting a Gaussian to this distribution gives $\sigma = 0\farcs132$, which corresponds to a full width at half maximum (FWHM) of $0\farcs31$. If we choose an arbitrary range of $\Delta\nu = \pm 0\farcs30$, 89% of the 160 pointings to either nod in LL2 fall within that range. For SL1, the percentage is likely to be even higher, because the offset errors in LL2 include the errors in SL1 and accumulated errors from shifts in the telescope between SL1 and LL2.

## 2.4 Testing the validity of a scalar SPITE correction

Sloan et al. (2003) modelled how the throughput varied not just as function of position, but also of wavelength. In SL1, the shorter wavelengths are not as sensitive to pointing errors, because the core of the Airy function is significantly smaller than the size of the slit. At longer wavelengths, parts of the core already fall outside the slit. Consequently, a small offset across the slit will move measurable

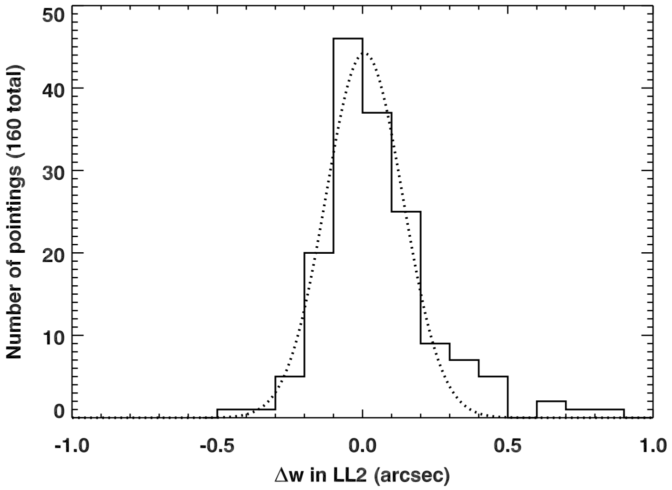

Figure 2 —The distribution of 80 observations of HD 173511 in the two nod positions in LL2 (total 160 pointings). The fitted Gaussian has $\sigma = 0\farcs132$, which gives a FWHM of $0\farcs31$. Ninety percent of the pointings fall within the FWHM.

flux out of the slit at longer wavelengths, while the entire core of the Airy disk remains inside the slit at shorter wavelengths. In fact, one side of the first Airy ring will move into the slit, actually *increasing* the measured flux at the shortest wavelengths.

To parameterize the shape of the spectra in the Double-star Experiment, we take the ratios of the flux in three wavelength regions: blue (7.5–8.5 $\mu$m), center (10.0–12.0 $\mu$m), and red (13.0–14.0 $\mu$m). The PSF is not perfectly symmetric, and the degree of asymmetry changes with wavelength. As Figure 3 illustrates, the position of maximum throughput, which we use to define the center of the SL1 slit, actually changes with wavelength. The blue wavelength range is most affected because more of the first Airy ring, which is more asymmetric than the core, appears inside the slit.

Figure 3 plots the flux ratios, all normalized to unity at the center of the slit, as a function of $\Delta v$ offset. The top two panels include data at the blue end of the spectrum, where the core of the Airy disk fits cleanly inside the slit. Thus, for small offsets, the spectra get bluer, since more flux is lost at longer wavelengths. At some point to either side of the center of the slit, the core of the Airy disk in the blue finally hits the edge of the slit, and the spectrum begins to redden again. The blue/red ratio provides the most critical test, as it measures the overall tilt in

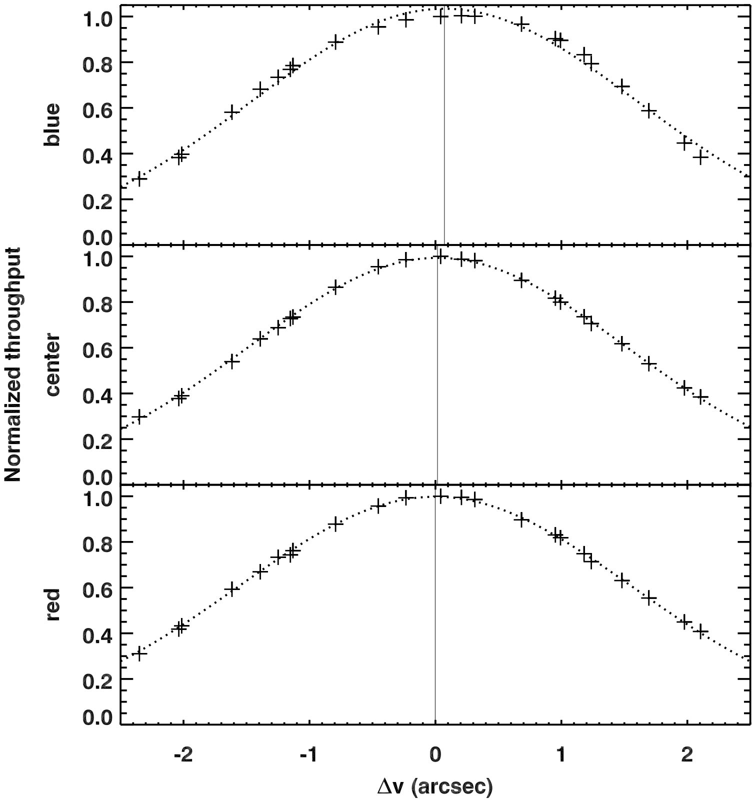

Figure 3 —The throughput in the slit for three separate wavelength ranges: blue (7.5–8.5 $\mu$m), center (10.0–12.0 $\mu$m), and red (13.0–14.0 $\mu$m). The center of the slit ($\Delta v$=0) is defined as the position of maximum throughput with using a broader wavelength range (8.8–14.0 $\mu$m). These data are for one of the two nod positions in SL1; the other nod gives similar results.

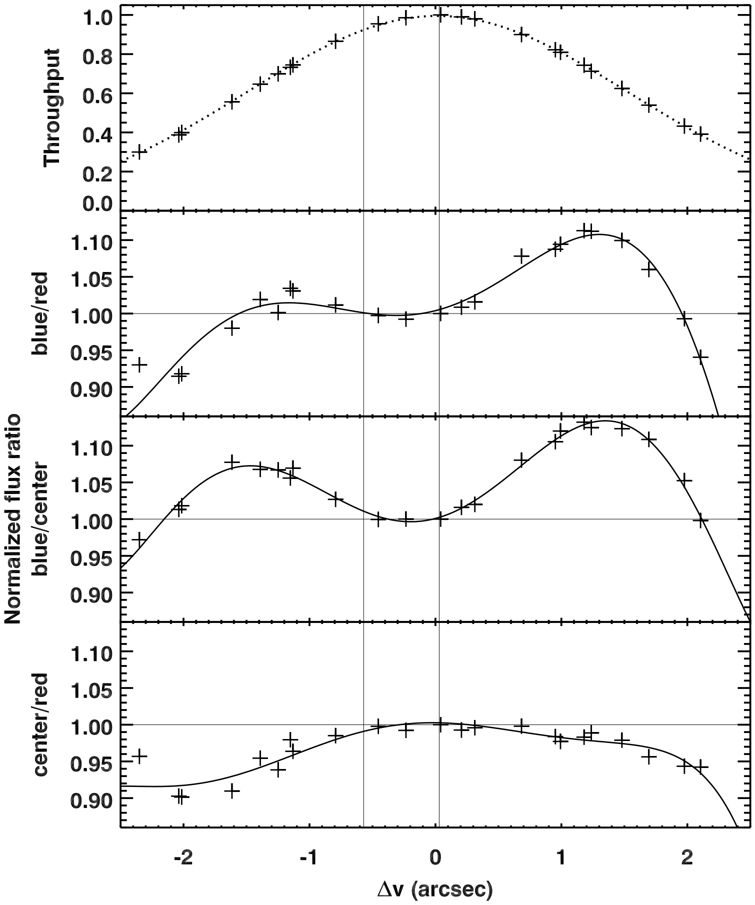

Figure 4 —Variations in the shape of the spectrum as a function of position across the slit ($\Delta v$) (bottom three panels), and the overall throughput (top panel) for data in the first nod position. The shape is parameterized as the ratio of the flux in the following wavelength ranges: blue (7.5–8.5 $\mu$m), central (10.0–12.0 $\mu$m), and red (13.0–14.0 $\mu$m). The solid curves in the bottom three panels show a polynomial fitted to the data. The dotted curve in the top panel is a Gaussian. The solid vertical lines mark the range of offsets that include 89% of the pointings, i.e. the average position $\pm 0\farcs30$. The average pointing is actually at $\Delta v = -0\farcs27$ in SL1, as explained by Sloan et al. (2004b).

the spectrum from one end to the other.

Sloan et al. (2004b) used the Double-star Experiment to show that the average pointing in SL1 was to a position with $\Delta v = -0.''27$. Coupling this with the results of the previous section, almost 90% of the pointings will fall between $-0.''6 < \Delta v < 0.''0$. The distortion in the shape of the spectrum in this range is always less than 2%, even though the throughput correction can be as large as 8% in this range.

These results lead to the conclusion that for the vast majority of observations with SL on the IRS, a scalar correction for spectral pointing-induced throughput errors will be sufficient.

# 3 A Correction Algorithm

The standard means of correcting for SPITE is to scale all of the low-resolution segments in a spectrum to eliminate discontinuities between them. Observers generally scale all segments up to match what is assumed to be the best centered segment. The variations in SL are readily understood in terms of SPITE, but the origin of the variations in LL is less clear. We propose here a method of correcting SL1 independent of any knowledge of the brightness of the source in LL2.

As described above, the position of a source *along* the LL2 slit provides a means of estimating position *across* the SL1 slit. This offset then gives a SPITE correction, either from Equations (1) and (2) or Figure 1. We have tested this algorithm on all pointings to the A dwarf δ U Mi and the K giant HD 173511 in IRS Campaigns 1–5. Both sources were observed repeatedly in this period are have shown no evidence for variability, either spectroscopically or photometrically.

For both sources, we also have spectral templates provided to the IRS team by Martin Cohen. These templates are based on spectra of brighter standard stars of the same spectral class and have been adjusted to fit the available photometry for δ UMi and HD 173511.

To test the algorithm, we measure the average flux in a SL1 spectrum and compare it to the template, both before and after making the SPITE correction. If the algorithm is valid, it should reduce the disagreement between the template and the actual spectrum to nearly zero. Table 1 presents the overall corrections for both δ UMi and HD 173511. For both stars, the average correction was 3.31%, bringing the mean throughput ratio to 0.982±0.031, i.e. better than 2%. For the spectra which were mispointed the worst ($\sim 0.''5$) the improvement was better than 5%. It should also be noted that the only cases in which the corrections made a

TABLE 1

SUMMARY OF CORRECTIONS FOR δUMI AND HD 173511

| \|Offset\| (in arcsec) | <Initial Ratio> | <Corrected Ratio> |
|---|---|---|
| δ UMi | | |
| >0.66 | 0.896±0.049 | 0.96±0.053 |
| 0.46–0.66 | 0.932±0.044 | 1.00±0.047 |
| <0.46 | 0.984±0.039 | 1.01±0.040 |
| HD 173511 | | |
| >0.66 | 0.866±0.043 | 0.940±0.047 |
| 0.46–0.66 | 0.930±0.046 | 0.956±0.047 |
| <0.46 | 0.967±0.039 | 0.980±0.040 |

NOTE.—An offset of 0.″66 corresponds to an average throughput ratio of 0.90, and an offset of 0.″46 corresponds to an average throughput ratio of 0.95.

spectrum worse were those where the error was less than 1% to begin with. In those cases, a SPITE correction may not be necessary.

# References

Sloan, G.C., Nerenberg, P.S., & Russell, M.R. 2003, IRS-TR 03001: The Effect of Spectral Pointing-Induced Throughput Error on Data from the IRS

Sloan, G.C. 2004, IRS-TR 04005: Using Orthogonal Slits to Investigate Spectral Discontinuities

Sloan, G.C., Keremedjiev, M.S., & Kasliwal, M.M. 2004, IRS-TR 04006: The Double-Star Experiment and Pointing to Short-Low Order 1