Infrared Spectrograph
Technical Report Series

IRS-TR 12001: Spectral Pointing-Induced Throughput Error and Spectral Shape in Short-Low Order 1

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Abstract

We investigate how the shape of a spectrum in the Short-Low module on the IRS varies with its overall throughput, which depends on how well centered a source is in the spectroscopic slit. Using flux ratios to quantify the overall slope or color of the spectrum and plotting them vs. the overall throughput reveals a double-valued function, which arises from asymmetries in the point spread function. We use this plot as a means of determining which individual spectra are valid for calibrating the IRS.

1   Introduction

The Infrared Spectrograph (IRS; Houck et al. 2004) on the *Spitzer Space Telescope* (Werner et al. 2004), like all slit spectrometers, suffers from the issue of slit throughput. As the position of a source within the slit varies, the amount of radiation from the source truncated by the edges of the slit also varies. The point-spread function (PSF) increases in size with wavelength, and the interactions of

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the Airy rings in the PSF with the slit edges make the throughput a complicated function of both telescope pointing and wavelength.

The IRS Team at Cornell has referred to this problem as Spectral Pointing-Induced Throughput Error, or SPITE. Even before the launch of the telescope in August, 2003, they were investigating both the impact of SPITE and its possible mitigation. Through the course of the mission, several IRS Technical Reports have addressed these issues. The very first of the reports, released a month ahead of launch, characterized the likely effect SPITE would have on the shape of observed spectra in all four IRS modules (IRS-TR 03001, Sloan et al. 2003). IRS-TR 04007 (Keremedjiev & Sloan 2004) found that the reconstructed pointing from the spacecraft did not have the accuracy needed to directly determine SPITE corrections, but IRS-TR 04005 (Sloan 2004) noted that the orthogonality of the Short-Low (SL) and (LL) slits made it possible to use the position of a source in the cross-dispersion direction (i.e. along the slit) in one module to estimate its position in the dispersion direction (across the slit) in the other.

IRS-TR 06001 (Keremedjiev & Sloan 2006) provided perhaps the most important result, that the distortion to the shape of the the SL Order 1 (SL1) spectrum was generally less than 2% for most pointings (i.e. pointings that caused a total loss of flux of 8% or less, compared to pointings in the center of the slit). The implication is that scalar corrections would generally suffice to produce accurate spectral shapes.

2   Observations and Analysis

Table 1—Calibration Data

Standard star	Spectral class	Observed in campaigns	AORs
HR 6348	K1 III	P–61 (intermittently)	84
HD 166780	K4 III	P–61 (intermittently)	41
HD 173511	K5 III	P–61	132
α Lac	A1 V	1–58 (intermittently)	28
δ UMi	A1 V	P–19 (intermittently)	43

This report concentrates on the large number of pointings to the five stars listed in Table 1. These five stars are the core standards used by the IRS Team at Cornell

for the low-resolution IRS modules. They account for 327 of the calibration observations with the IRS. Among other things, they provide us with a large sample of pointings randomly distributed about the center of the spectroscopic slits.

We will focus on the 1st-order SL slit (SL1). SL is much more susceptible to pointing errors than LL because its slit is $\sim$3 times narrower, $3.''6$ vs. $10''$, compared to typical pointing errors of $\sim0.''5$. Within SL, the larger PSF in SL1 means that SPITE will be more of a problem for typical pointing errors than in SL2.

Our immediate objective is identifying those SL pointings that should not be included when combining spectra from the many observations for calibration purposes. In the process, we have uncovered evidence that the PSF is asymmetric in the dispersion direction, with clear consequences for which spectra have distorted shapes and should not be used in calibration.

Each Astronomical Observing Request (AOR) includes two pointings in SL1, which we treat as separate measurements. For each pointing, we measure the mean flux density from 7.5 to 14.0 μm to assess the total throughput from the star (F_ν units, weighted by a $1/\lambda^2$ to evenly weight data at all wavelengths). To estimate the impact of SPITE on the shape of the spectrum, we also consider the ratios of the mean flux density in the following three wavelength regions: 7.5–9.5, 9.5–11.5, and 11.5–14.0 μm.

Figures 1 and 2 plot the flux ratios for the intervals 11.5–14.0 μm over 7.5–9.5 μm as a function of the mean flux density over the larger 7.5–14.0 μm window. For each source, we normalize the results by ignoring the three brightest spectra and averaging the next five. To simplify our discussion, we will refer to the quantities plotted as color vs. flux.

3   Discussion

Figure 1 and 2 reveal a double-valued dependence of color with flux, with two significantly different colors possible for a given reduction in flux. Following the upper trace, as the flux drops, the color actually grows redder before beginning a steady, but slow change to the blue. Even at 92% relative throughput, the change in color is less than 1%. The lower trace, however, quickly grows bluer as the overall throughput drops.

The general trend to bluer colors with less throughput results from the increasing size of the PSF with wavelength. An offset of the source from the center of the slit preferentially removes flux from the red end of the spectrum compared to
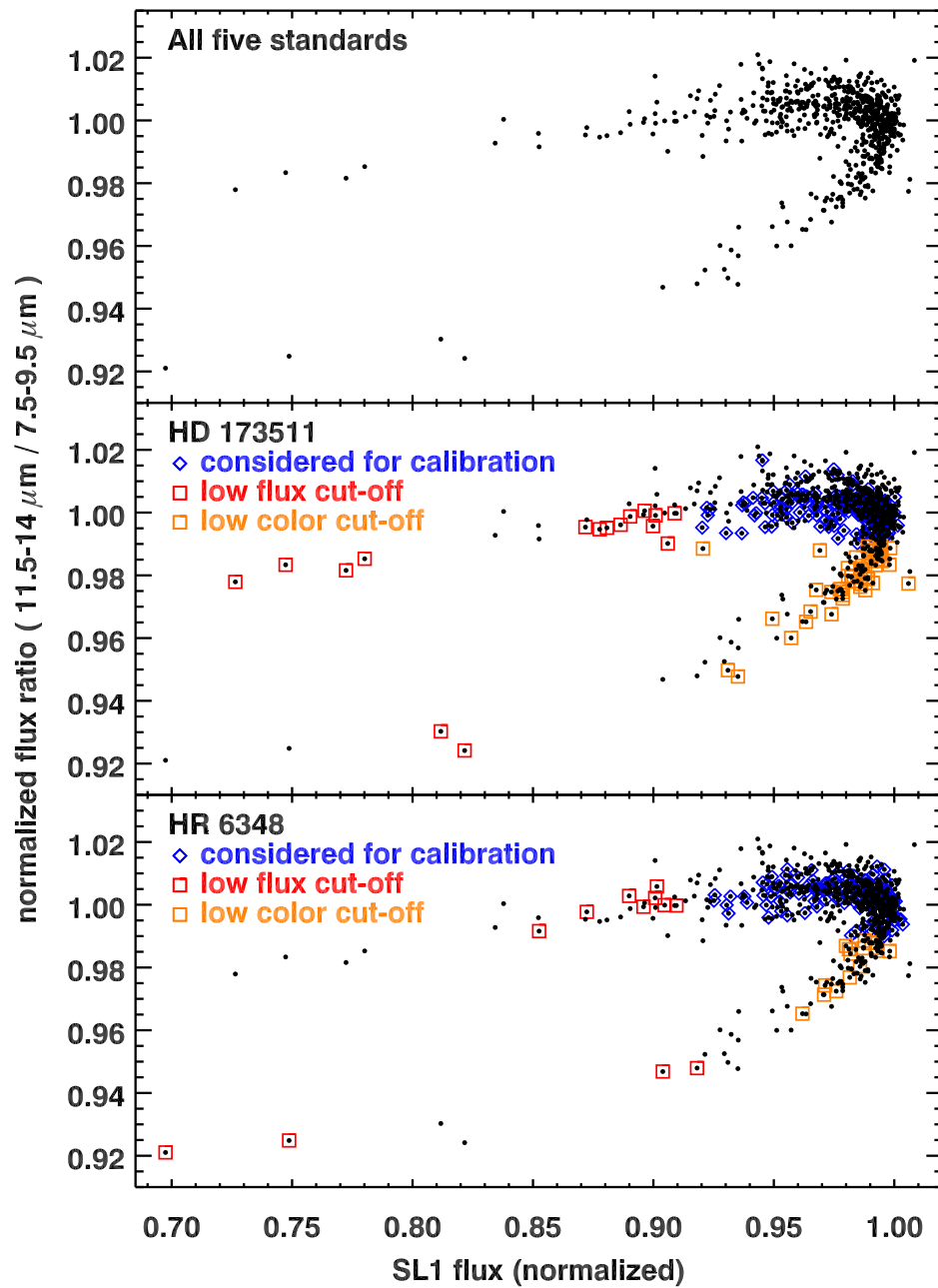
Figure 1 —Normalized color vs. flux for (top to bottom): all five standard stars considered, HD 173511, and HR 6348. The data for a particular star are color coded based on whether they fail the flux criterion (0.92), the color criterion (0.99), or pass both.
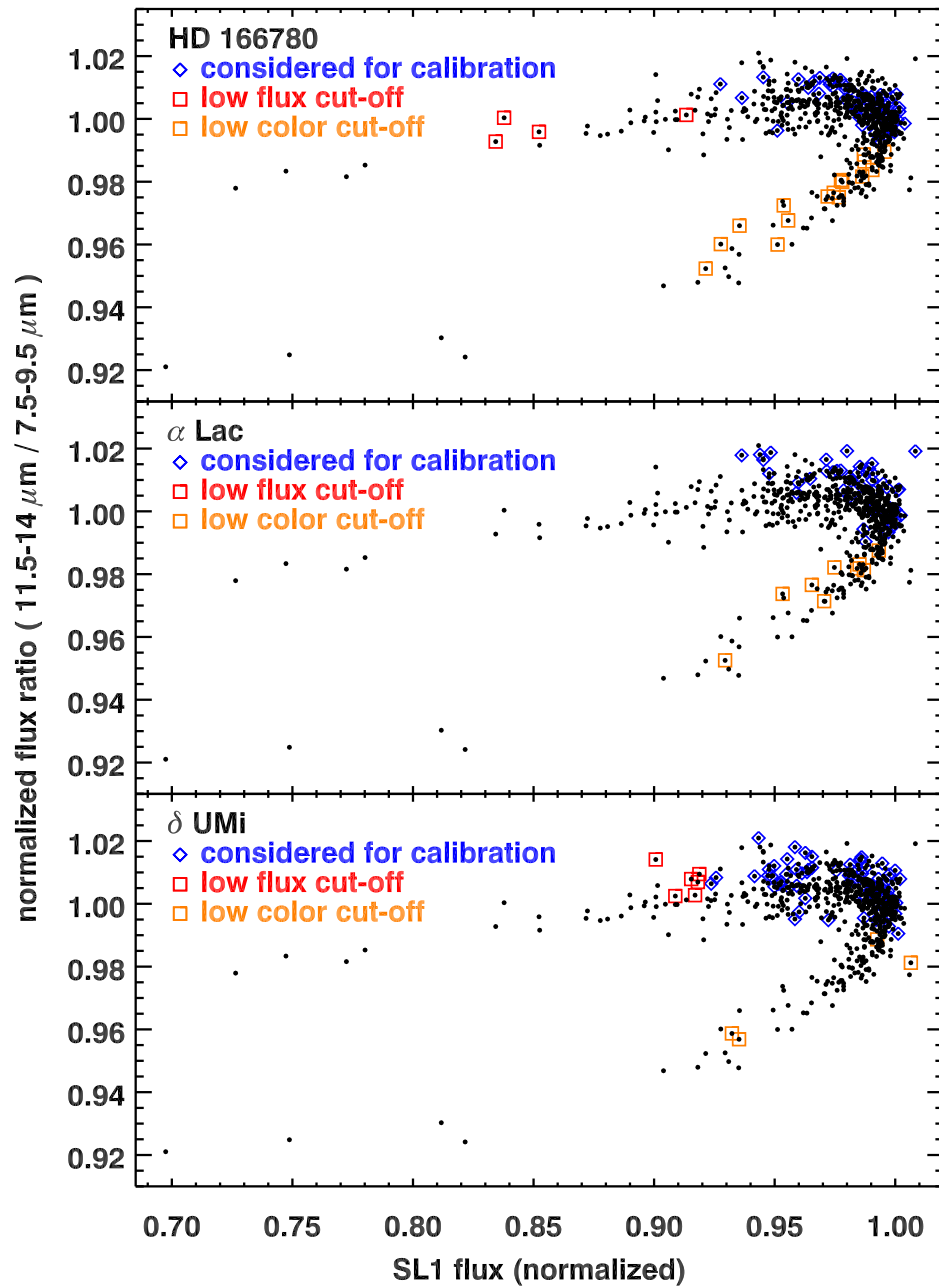
Figure 2 —Normalized color vs. flux for (top to bottom): HD 166780, α Lac, and δ UMi. The symbols are as defined in Fig. 1.

the blue.

IRS-TR 03001 predicted the small increase in red flux compared to the blue for slight offsets from the center of the slit. At long enough wavelengths, the first Airy ring is partially truncated by the slit edges. Shifting the source to slightly off-center pulls the Airy ring on one side back into the slit. If the PSF is asymmetric, then this effect may be more pronounced for shifts in one direction compared to the other.

To demonstrate that the two arms in Fig. 1 and 2 arise from offsets in different directions in the dispersion direction in SL, we can take advantage of the nearly orthogonal angles between the long axes of the slits in SL and LL. IRS-TR 04005 showed that the pointing errors accumulated between the SL and LL observations were small enough to allow the position *along* the LL slit to serve as a proxy for position *across* the SL slit.

The worst four pointings on the upper arm in Fig. 1 and 2 correspond to two HD 173511 AORS with a mean offset of -0.16 pixels from the nominal nod position in LL2, where we define zero as the left-hand side of the LL spectral images. The worst four pointings on the lower arm are from two AORs, one of HD 173511 and one of HR 6348; the mean offset here is $+0.23$ pixels. Translating to angles on the sky, these are $-0\rlap{.}''79$ and $+1\rlap{.}''17$, respectively.

The next worst group of pointings on the two arms give similar results. Here we will use the next six pointings, using flux as the criterion on the upper arm and color as the criterion on the lower. The six pointings on the upper arm are from five AORs of HD 166780, HR 6348, and HD 173511, and their mean offset is -0.05 pixels, or $-0\rlap{.}''26$. The six pointings on the lower arm are from four AORs. Three are of the same sources just listed; the fourth is of α Lac. Their mean offset is $+0.06$ pixels, or $+0\rlap{.}''29$. It is worth noting that even this far away from the center of the distribution, the offsets in LL2 are beginning to overlap. The implication, unfortunately, is that the pointing errors accumulated during an AOR will be large enough to prevent us from predicting the throughput in SL from the LL positions with enough accuracy to be useful in all but the most extreme cases.

Table 3—Rejected and Retained Pointings

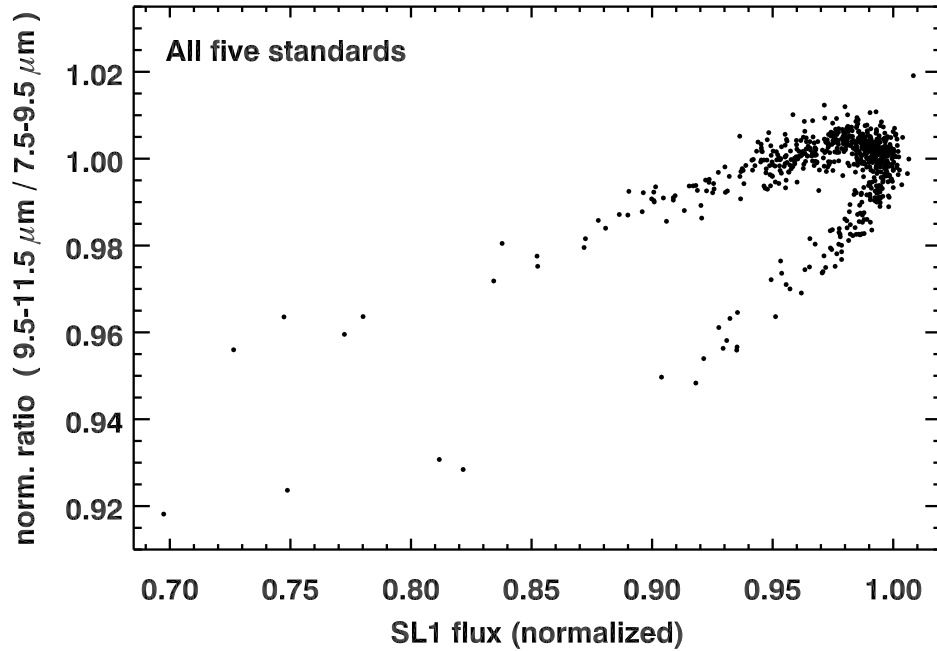| Standard star	Spectral class	SL1 pointings	Below flux limit	Below color limit	Retained
HR 6348	K1 III	168	12	15	151
HD 166780	K4 III	82	4	17	61
HD 173511	K5 III	264	16	58	190
α Lac	A1 V	56	0	9	47
δ UMi	A1 V	86	6	4	76

Figure 3 —As Fig. 1 and 2, except that the color intervals have been shifted to 9.5–11.5 μm (the central interval) and 7.5–9.5 μm (the blue interval). The flux in the central interval decreases more than the red or blue intervals, resulting in a sharper drop in color with decreasing flux compared to Fig. 1 and 2.

The distribution of fluxes and colors for the sources provide a quantitative means of consistently identifying mispointed observations and excluding them from the calibration of the SL module. We have chosen a normalized flux limit of 0.92, based originally on IRS-TR 06001. In order to maintain good consistency in the end-to-end slope of the SL1 data, we will reject any pointings below a

normalized color of 0.99. The sources which fall below these limits are color coded in Fig. 1 and 2. Table 2 provides counts of rejected pointings for each of our five primary standards. Observations which pass this test might still be rejected if visual inspection reveals other artifacts or problems.

Figure 3 presents a color-flux plot similar to Fig. 1, except that the color has been shifted to the ratio of the central interval (9.5–11.5 μm) over the blue interval (7.5–9.5 μm). This version of the color-flux plot shows similar bahavior as before, except that this color decreases more quickly as the overall flux decreases. The cause is a greater loss of flux in the central wavelength region in SL1 than at either end of the spectrum. The *Spitzer* Science Center refers to this problem as "Curvature in SL1" in the IRS Instrument Handbook (see Sec. 7.3.3). It is only an issue for significantly mispointed spectra. As Fig. 3 illustrates, spectra on the upper arm do not show a curvature of more than 1% unless the overall throughput is down by $\sim$10%. On the lower arm in Fig. 3, the curvature is more of a problem, but that arm is not very well populated. For our selection criteria of 0.92 in overall flux and 0.99 in color (11.5–14 μm/7.5–9.5 μm), the curvature is never worse than $\sim$2%.

References

Houck, J.R., et al. 2004, *ApJS*, **154**, 18.

Keremedjiev, M.S. & Sloan, G.C. 2004, "IRS-TR 04007: Measuring the Precision of Reconstructed Pointing."

Keremedjiev, M.S. & Sloan, G.C. 2006, "IRS-TR 06001: Correcting Spectral Pointing-Induced Throughput Error in Short-Low Order 1."

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"

Spitzer Science Center 2011, "The IRS Instrument Handbook, V.5.0" (Pasadena: Caltech)
http://irsa.ipac.caltech.edu/data/SPITZER/docs/irs/irsinstrumenthandbook/

Werner, M.W., et al. 2004, *ApJS*, **154**, 1.