Infrared Spectrograph
Technical Report Series

IRS-TR 03003: Correcting for Spectral Pointing-Induced Throughput Error

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Abstract

We propose a method to correct for spectral pointing-induced throughput error (SPITE) when the observer has an accurate estimate of the expected spectrum from a source. By comparing the shape of a spectrum observed to that expected, one can estimate the offset of a source and correct for the resulting SPITE. The spectral data are weighted to maximize the sensitivity of the method for determining the offset. This method will be most useful for observations of standard stars.

1 Introduction

The Infrared Spectrograph (IRS) aboard SIRTF uses slits which are too narrow to allow all radiation from a source to pass through to the detector arrays. The location of a source within a slit influences the overall shape (tilt) of its spectrum. In general the long-wavelength end of the observed spectrum will suffer more attenuation than the short-wavelength end as the source moves toward the edge of the slit. This effect is due to the increasing size of the point spread function (PSF) at longer wavelengths.

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IRS-TR 03001 identifies this problem as Spectral Pointing-Induced Throughput Error (SPITE) and quantifies its relation to offsets of a target from the center of the slit due to pointing errors. It also identifies possible methods for correcting observed spectra for SPITE. This report follows up on IRS-TR 03001 by developing a means of correcting for SPITE.

This report presents two related methods of correcting an observed spectrum for SPITE, both of which require pre-existing knowledge of the observed spectrum. Thus, the methods described here are most suitable for well characterized targets, particularly standard stars.

For a star with a known spectrum, we can estimate the summed flux over the full wavelength range available to a module, or a single order in a module, or even a smaller range of wavelengths within an order. Since Short-Low (SL) has two separate apertures and the pointings to these two slits are semi-independent, we will treat SL2 and SL1 as separate modules. The same is true for Long-Low (LL). In Short-High (SH) and Long-High (LH), all ten orders are illuminated with the star in a single aperture.

The first method estimates the offset by comparing the total flux observed in a module with the expected value. The second method uses changes in the shape of the spectrum to determine the offset.

In the following discussion, we will use three expressions first defined in IRS-TR 03001. The Spectral Pointing-Induced Throughput, or SPIT, is the fraction of light incident on the telescope which reaches the detector array, and it is a function of wavelength. SPIT also depends on the position of a source within the slit, primarily the offset in the dispersion direction, perpendicular to the long axis of the slit (Δw). The SPIT ratio is the SPIT at a given offset, divided by the SPIT for a source centered in the slit ($\Delta w = 0\farcs0$). The SPIT error, or SPITE, is the SPIT ratio expressed as a percentage error.

2 Analysis

IRS-TR 03001 presents a model to estimate SPIT as a function of wavelength for each module. That report illustrates how the shape of a spectrum will change as the target is offset away from the center of the slit. We present a method to quantify this tilt in the spectrum by ratioing two or more summed spectral subregions for each module. The observed ratios can be used to (1) determine the actual offset of the source during the observation, and (2) use this offset to correct the observed spectrum to the amplitude and shape it would have if it were centered the slit.

We generate a look-up table for each module, with the SPIT calculated for each wavelength element in each order at offsets ranging from 0.″0 to 2.″0 in 0.″1 increments. To generate the flux ratios plotted in the figures below, we sum the SPIT over the given wavelength ranges and take a ratio of the summed SPIT in these wavelength ranges to quantify the tilt in the spectrum induced by the offset from the center of the slit. These ratios are normalized by dividing by the corresponding ratio for an offset of 0.″0.

For SL and LL, the SPIT correction must be determined separately for the two apertures. We have chosen two to three wavelength intervals within each order. For SH and LH, we have summed either one or two orders for each interval.

The general strategy when choosing wavelength intervals is to find one region that contains or is close to a minimum in the SPITE as a function of wavelength and another near the maximum. As detailed in IRS-TR 03002, the initial transmission correction to be used during IOC/SV contains spectral features which may be artifacts. We have avoided wavelength ranges where these artifacts may be present. We have also avoided spectral regions with relatively poor signal/noise (S/N) ratios or containing spectral features which may cause the observed spectra to deviate from the assumed spectra we are using for our standard stars.

2.1 Short-Low

Figure 1 shows that the total flux incident on SL1 drops by only $\sim$3% out to an offset of 0.″5, but beyond this point it drops more rapidly. The wavelength ranges 10.5–12.0 μm and 13.75–15.25 μm provide a straightforward means of determining the offset, as shown in Figure 2, but the offset must be 1.″0 or greater before the tilt in the flux ratio exceeds 1%. Because both curves are monotonic, any significant offsets should be unambiguous, and we can use the offset as determined from the total flux to check the offset found from the flux ratio.

In SL2 the offsets will be more difficult to diagnose. The total flux does not deviate by more than 1% until the offset is 0.″8 (Fig. 3). Two problems hamper the use of the flux ratios. First, many of the standard stars are K giants which have CO and SiO absorption bands in their spectra. These bands can absorb 10–15% of the total flux in some cases, and the precise strength and shape of the bands may prove difficult to predict. Wavelengths shorter than roughly 5.75 μm fall in the CO fundamental, and by 7.25 μm, the effects of the SiO fundamental become noticeable. This leaves only the region from 5.75 to 7.25 μm, which we have divided into three segments: 5.75–6.25, 6.25–6.75, and 6.75–7.25 μm. Figure

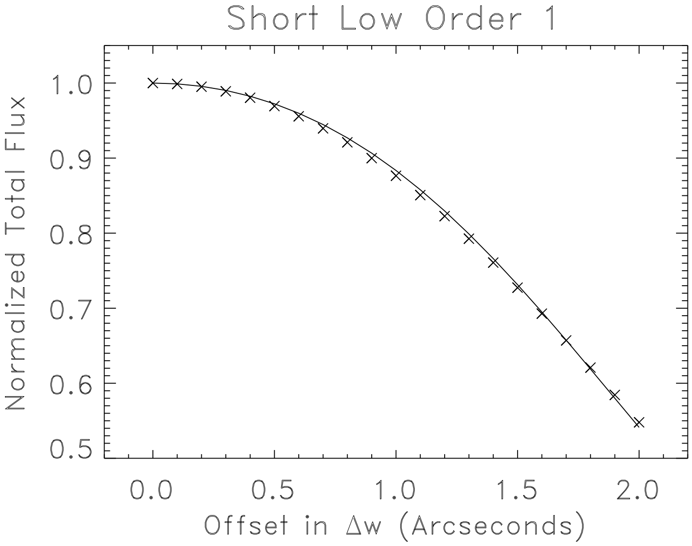

Figure 1 The normalized total flux on SL1 as a function of offset from the central axis of the slit. The crosses show the behavior for an input spectrum with the same brightness at all wavelengths. The solid line shows how the flux from a naked star (modelled with a Rayleigh-Jeans tail) would depend on offset.

4 plots the three possible flux ratios from these segments. Second, as Figure 4 shows, some flux ratios can be generated by two offsets. For example, a flux ratio of 0.99 ($F_{7.0\mu\mathrm{m}}/F_{6.0\mu\mathrm{m}}$) could correspond to an offset of either $0.''65$ or $1.''45$, but if the total flux is 80% of the expected value, then we know that the offset is closer to $1.''45$.

If the assumed spectrum for a K giant does not accurately portray the actual strength of the molecular bands, this will add an error to the measure of total flux on the array. This complication must be considered when correcting SL2 for SPITE.

The architecture of SL provides another means of checking the relative offset between SL1 and SL2. When a spectrum is in the first-order aperture, it will produce a first-order spectrum as well as what is described as the bonus order, which covers a wavelength region overlapping part of the second-order spectrum. This overlap provides an independent means of checking the relative offsets between the two orders. We do not yet have reliable transmission functions for the bonus orders (see IRS-TR 03002), and we recommend waiting for these data before using the bonus orders for SPITE corrections.

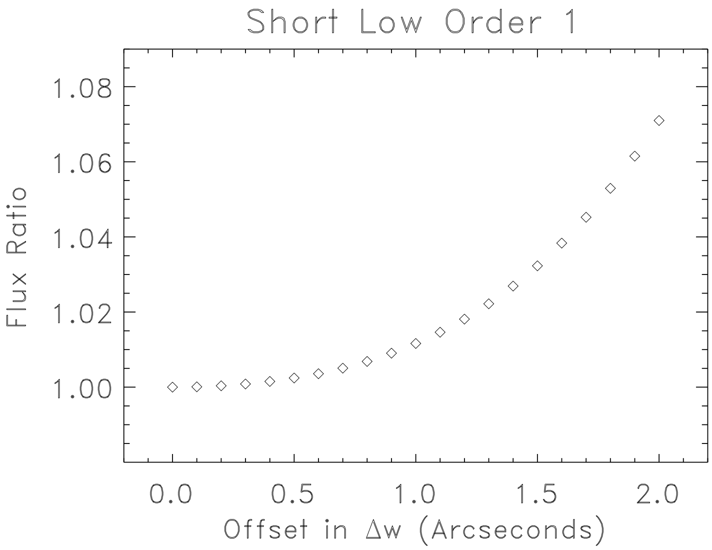

Figure 2 The flux ratio ($F_{10.5-12.0\ \mu\mathrm{m}}$ $/F_{13.75-15.25\ \mu\mathrm{m}}$) as a function of offset.

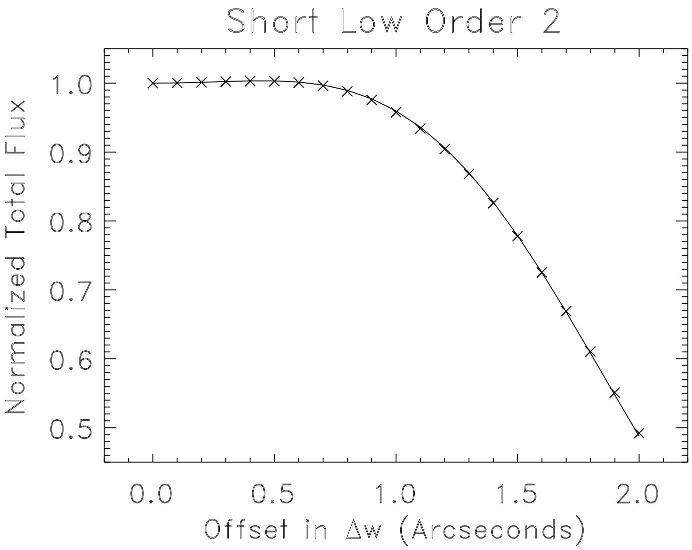

Figure 3 The normalized total flux on SL2 as a function of offset for a uniform spectrum (crosses) and a naked star (solid line, using a Rayleigh-Jeans tail).

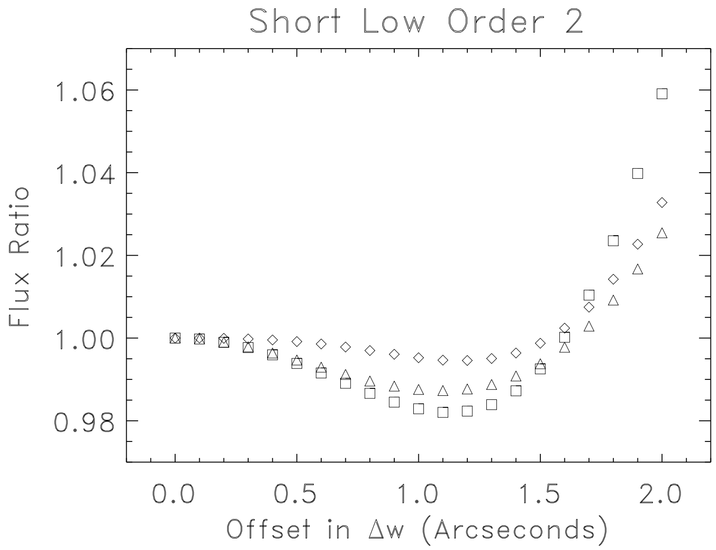

Figure 4 Flux ratios on SL2 as a function of offset. Squares are for the ratio $F_{6.75-7.25\,\mu\mathrm{m}}/F_{5.75-6.25\,\mu\mathrm{m}}$, triangles for $F_{6.75-7.25\,\mu\mathrm{m}}/F_{6.25-6.75\,\mu\mathrm{m}}$, and diamonds for $F_{6.25-6.75\,\mu\mathrm{m}}/F_{5.75-6.25\,\mu\mathrm{m}}$.

2.2 Short-High

For SH we can average over whole orders instead of limited wavelength ranges. We selected orders 14 and 19. Ideally, we would have liked to select order 11 or 12 for the long wavelength range, but the transmission from the optics may produce spectral artifacts in these orders which might complicate the calibration. IRS-TR 03002 discusses the potential artifacts in the wavelength ranges covered by orders 11 and 12. Figure 5 shows how the total flux decreases with offset, and Figure 6 plots the flux ratio (F_{19}/F_{14}) vs. offset. The flux ratio is reasonably sensitive to offset, and while there is a degeneracy beyond $1\overset{''}{.}5$, these offsets should be quite rare, and they could still be resolved using the total flux.

2.3 Long-Low

Figures 7 and 8 plot the behavior of the total flux and flux ratio, respectively for LL2, and Figures 9 and 10 do the same for LL1. The dominant result is that the spectral tilts at these longer wavelengths are much smaller than in SL or SH, due primarily to the larger slit width. The tilt in LL2 is less than 2% out to an offset of $2\overset{''}{.}0$, and in LL1 it is less than 1%. The total flux is slightly more sensitive, with a

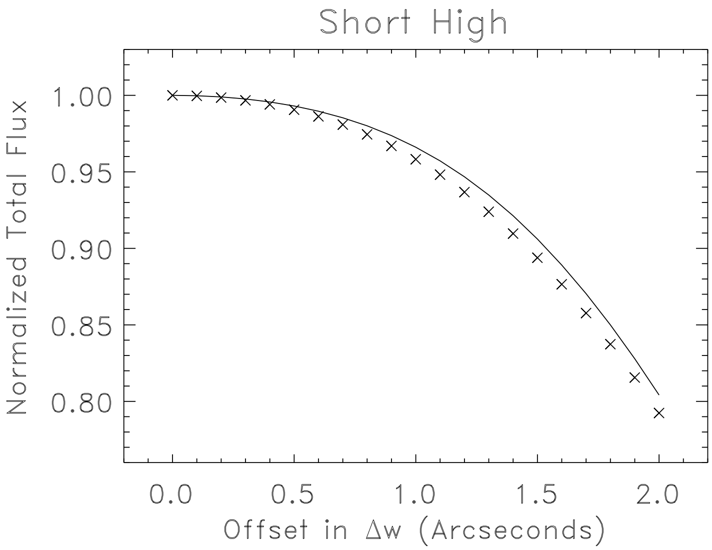

Figure 5 The normalized total flux on SH as a function of offset for a spectrum with constant flux at all wavelengths (crosses) and a naked star (solid line, modelled with a Rayleigh-Jeans tail).

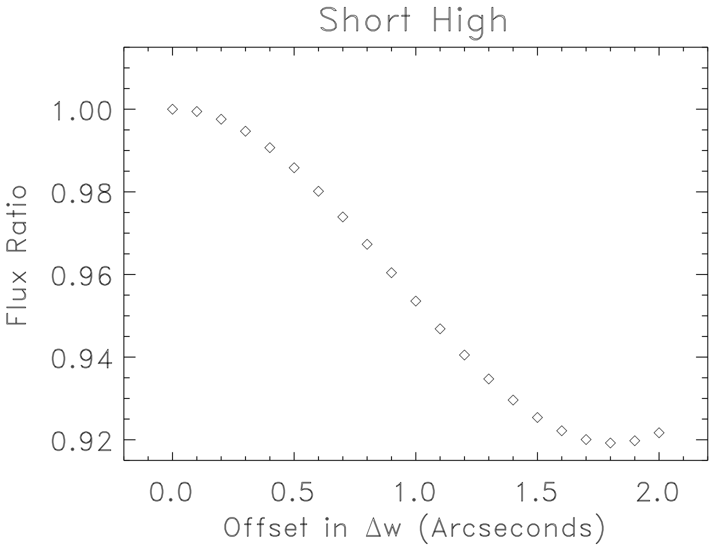

Figure 6 The flux ratio (F_{19}/F_{14}) as a function of offset.

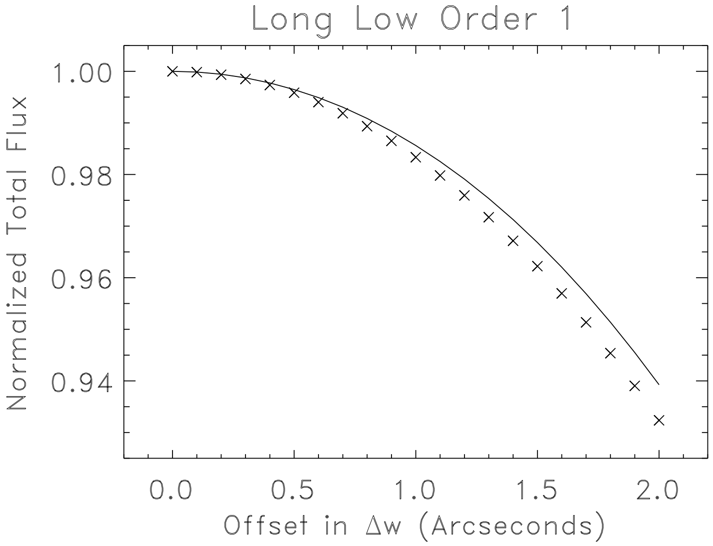

Figure 7 The normalized total flux on LL1 as a function of offset for a uniformly bright spectrum (crosses) and a Rayleigh-Jeans tail (solid line, mimics a naked star).

drop of 6% for a $2''.0$ offset in LL1.

We sum the fluxes for the ratios in LL2 over the ranges 15.75–17.25 μm and 19.0–20.5 μm. For LL1 the ranges are 30.0–34.0 μm and 36.0–40.0 μm. We would have preferred to have the longer wavelength region in LL1 cover 38.0–42.0 μm but possible artifacts and poor S/N $\sim$40 μm forced us to shorter wavelengths.

Like Short Low, Long Low also has a bonus order, allowing a means of checking the relative offsets between LL1 and LL2.

2.4 Long-High

As with SH, we elected to average over entire orders for LH. Because the wavelength coverage is broader in Long High, particularly in the low orders, we elected to average over two orders at shorter wavelength (17 and 18) and then compare that with the average over order 11. Again, the large slit width leads to smaller SPITE, with a variation out to an offset of $2''.0$ of only $\sim$2% in total flux and 5.5% in flux ratio. For a source with a flat spectrum, the loss in total flux at $2''.0$ offset would be $\sim$3%.

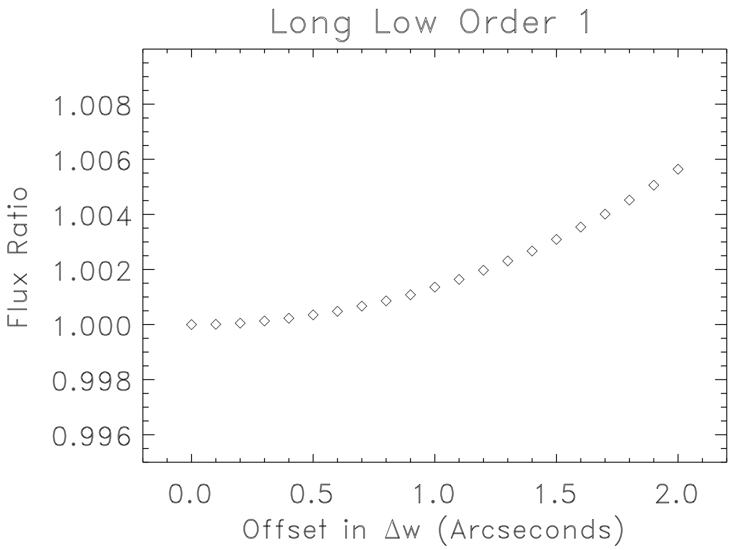

Figure 8 The flux ratio ($F_{30-34.0\ \mu\mathrm{m}}\ /F_{36-40\ \mu\mathrm{m}}$) as a function of offset.

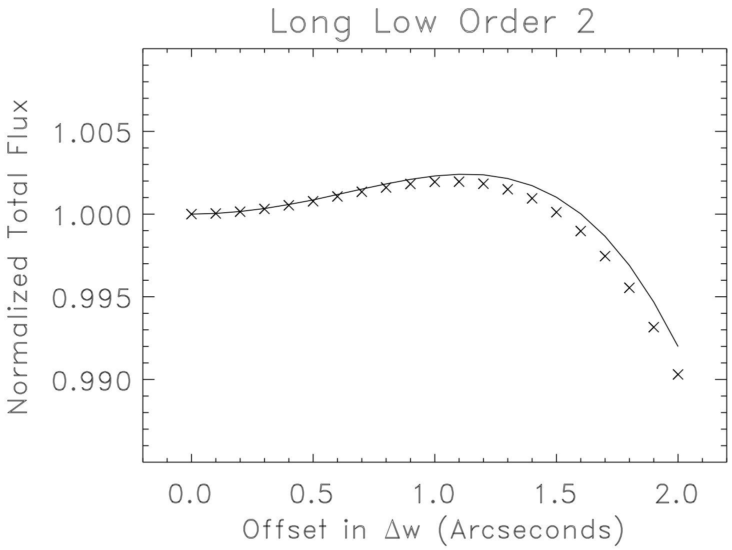

Figure 9 The normalized total flux on LL2 as a function of offset for a uniformly bright spectrum (crosses) and a Rayleigh-Jeans tail (solid line, mimics a naked star).

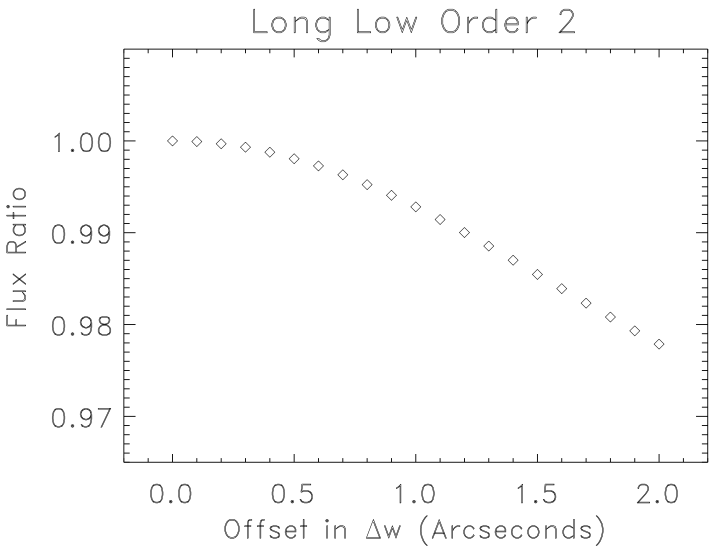

Figure 10 The flux ratio ($F_{15.75-17.25\ \mu\mathrm{m}}\ /F_{19.0-20.5\ \mu\mathrm{m}}$) as a function of offset.

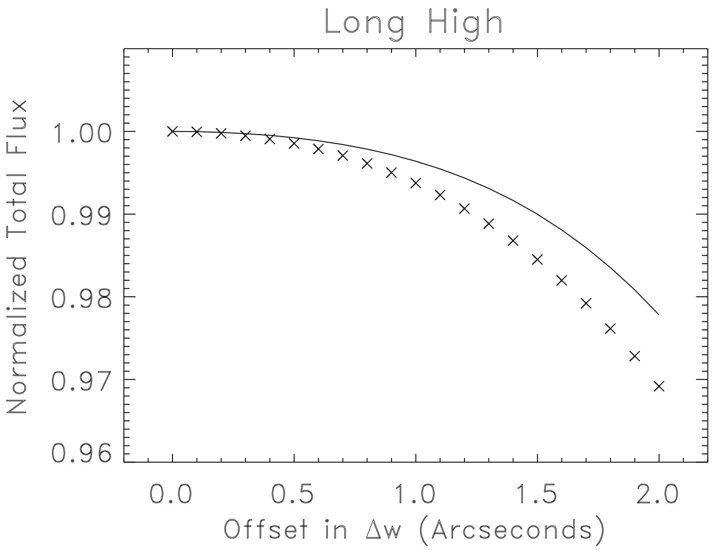

Figure 11 The normalized total flux on LH as a function of offset for a uniformly bright spectrum (crosses) and a naked star (solid line, using a Rayleigh-Jeans tail).

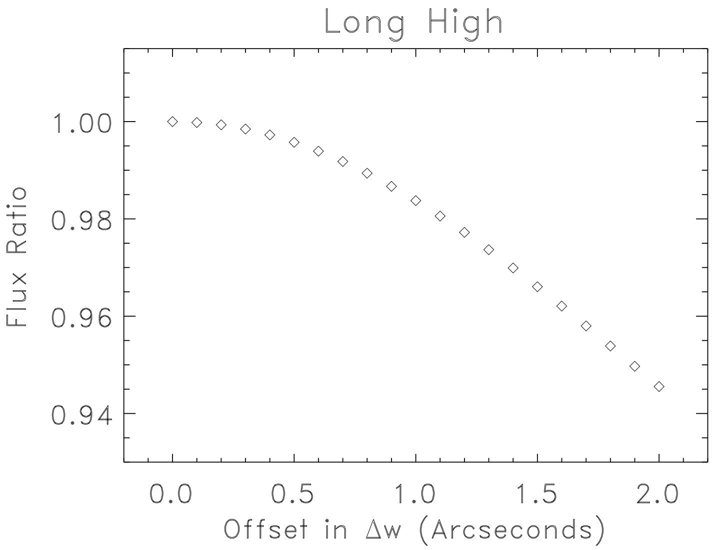

Figure 12 The flux ratio (F_{17-18}/F_{11}) as a function of offset.

3 Conclusion

For spectra obtained after a high-accuracy peak-up (HP1), about 68% of the pointing offsets in the dispersion direction (Δw) will be $0\farcs4$ or less for a gaussian distribution. IRS-TR 03001 presented the maximum SPIT errors expected for each module for these offsets. The maximum 1σ error is 2.5% in SL, but the limitations to the wavelengths we can use for diagnostics reduce the deviations expected in our flux ratios to less than 1%. While we can expect to obtain a S/N of 100 or more for fluxes integrated over the wavelength ranges we have defined, it is not yet demonstrated that we will be able to make SPITE corrections for typical pointing errors obtained using HP1.

During IOC/SV, our demonstration of the techniques described here may be limited to those cases where the pointing offsets in the dispersion direction are substantially larger than the typical 1σ error of $0\farcs4$. In IRS Campaign P, the spectrophotometric calibration activity IRS-070 will observe 9 stars with SL, obtaining a total of 18 independent pointings (not distinguishing the two nod positions per pointing). Thus, we can expect roughly six of these to be outside the $0\farcs4$ limit, and perhaps one to be outside the 2σ limit of $0\farcs8$. Additional standards observed in other activities will increase the number of pointings to be examined and potentially corrected. These observations will provide a useful means of testing the method of correction proposed here.

In closing, one should note that other methods for estimating the pointing offset and generating a SPITE correction are also possible. For example, one could use the total flux on one of the peak-up sub-arrays on SL to estimate the total flux of a source in the 16 or 22 μm bandpasses and then compare this measurement to the integrated spectrum from the relevant wavelength ranges in other modules to estimate the offset. We have also noted that the bonus order may prove useful. These methods may merit further study in the future.

References

Nerenberg, P.S., & Sloan, G. C. 2003, IRS-TR 03002: New Transmission Functions for the IRS Modules

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