Infrared Spectrograph
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IRS-TR 03001: The Effect of Spectral Pointing-Induced Throughput Error on Data from the IRS

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Abstract

We have simulated the effect of spacecraft pointing on the fraction of flux from an astronomical source which will pass through a slit on the Infrared Spectrograph on SIRTF. We show that calibrating for throughput assuming that a source is always centered in the slit will result in errors of several per cent for a significant fraction of observations using high accuracy peak-up (HP1). When using moderate accuracy peak-up (HP2), the relative throughput errors exceed 25% for a 5% of the observations with Short Low. These errors are generally more severe for the short-wavelength modules, and thus observations with these modules should use HP1 peak-up if spectrophotometric calibration is important.

1 Introduction

In all four modules in the Infrared Spectrograph (IRS), the slit is narrow enough compared to the size of the point spread function (PSF) that a significant fraction of the core of the PSF cannot pass through the slit. Therefore, the throughput of the slit depends on the location of a source within

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†Equation (1) corrected 18 August, 2006; thanks to Alex Kitt for pointing this error out.

the slit, which will be determined by the pointing of the spacecraft and our knowledge of the location of the slit. This report describes our method for estimating the throughput of the IRS slits as a function of both wavelength and source position, and it also illustrates the effect that pointing-induced throughput will have on the spectrophotometric calibration of spectra.

We define the spectral pointing-induced throughput (SPIT) to be the fraction of flux from a source that passes through the slit. SPIT is a function of wavelength and position of the source within the slit. Further, we define the spectral pointing-induced throughput error (SPITE) as follows. The SPIT ratio is the ratio of the SPIT for a given source position to the SPIT for a source centered exactly in the slit. The SPITE = 1− SPIT ratio.

The routine processing of IRS data will assume that a source is centered in the slit. However, a typical source will be offset by some amount from the center of the slit due to random pointing errors, and this offset will lead to a wavelength-dependent error in the apparent strength of the spectrum. This error is the SPITE, and the current method of spectrophotometric calibration does not account for it.

We investigate the magnitude of the SPITE problem with the ultimate objective of developing a means of correcting for it.

2 Method

We estimate the PSF from SIRTF using equation 10.1.10 from Schroeder (1987):

$$\mathrm{PSF} = \frac{1}{(1-\epsilon^2)^2}\left[\frac{2\,J_1(v)}{v} - \epsilon^2 \frac{2\,J_1(\epsilon v)}{\epsilon v}\right]^2 \tag{1}$$

where ϵ is the linear obscuration ratio (diameter of secondary/diameter of seconday and v is a dimensionless quantity defined as

$$v \equiv \frac{\pi\, D(\mathrm{m})\, \theta(\mathrm{rad})}{\lambda(\mathrm{m})} = 15.231\, \frac{D(\mathrm{m})\, \theta(\mathrm{arcsec})}{\lambda(\mu\mathrm{m})} \tag{2}$$

This equation accounts for the circular aperture of the telescope and the circular obscuration of the secondary mirror. We have used 0.85 m as the diameter of the telescope and 0.33 as the obscuration ratio. We make no attempts at this time to correct for deviations from circular symmetry in the PSF or any smearing of the PSF due to telescope jitter.

Table 1
Slit dimensions (arcsec)

Module	Pixel size	Dispersion	Cross-dispersion
SL	1.8	3.6	55.0
SH	2.4	4.8	12.1
LL	4.8	9.7	145.0
LH	4.8	9.7	24.2

Our algorithm generates a PSF at each wavelength observed by each module (in 0.1 μm increments), and then convolves the PSF with a rectangular slit for positions every 0.1 arcseconds from the center of the slit in the dispersion direction. The results are saved in look-up tables. Table 1 gives the slit dimensions assumed for each module.

For each module, we generate random offsets from the center of the slit in both the dispersion and cross-dispersion directions such that they fit a gaussian distribution with a 1-σ radial error of 0.54 arcseconds for Hard-point 1 (HP1) and 1.00 arcseconds for Hard-point 2 (HP2). A star with zero offsets would be centered in the slit, in both the dispersion and cross-dispersion directions. The throughputs depend on the offset in the dispersion direction (narrow slit axis), and they are interpolated from the look-up tables (which give results for every 0.1 arcseconds).

We produce synthetic spectral images using as input a spectrum with the same flux at all wavelengths, corrected in each module for SPIT, and using the wavsamp files supplied by the SIRTF Science Center to map the orders onto the array.

One-dimensional spectra are extracted from each order of each module by iterating along the order (i.e. through row numbers) and summing all columns belonging to a given order in each row. This method of extraction does not account for the angle between a curve of constant wavelength and the row-axis of the array. Given that the input spectra are identical at all wavelenghths and the SPIT varies gradually with wavelength, this crude method should not present any problems.

3 Results

We present the results of our simulated images as spectra in the form of SPITE for each module. Recall this is the ratio of the throughput for a given position divided by the throughput for a source centered in the slit. Because the spectral correction will apply for a centered source, the SPITE is the best means of measuring the error produced in the spectrum as a result of a pointing offset from the center of the slit.

Each figure includes four panels, one for each module. The upper curve in each panel is the SPITE for the 1-σ position in the distribution of offsets in the dispersion direction. Thus, 68% of the pointings in a random distribution will be closer to the center of the slit (in the dispersion direction). The lower curve represents the 2-σ position (95%); one can expect that one pointing in 20 will result in larger spectral pointing-induced througput errors.

Figure 1 illustrates the effect of SPIT for expected 1-σ and 2-σ observations using high-accuracy peak-up (HP1) by plotting the SPIT ratio as a function of wavelength. HP1 should provide a distribution of offset errors with a radial 1-σ value of 0.54". This corresponds to 0.38" in the dispersion direction. We calculated pointings for the two slit positions in the low-resolution slits separately, and for each slit, we made 100 random pointings.

Figure 2 illustrates the results of the simulated images using moderate-accuracy peak-up (HP2), which would provide a distribution with a 1-σ radial offset of 1.00" and offset in the dispersion direction of 0.71". Here, one pointing was used simultaneously for both slits in Short-Low and Long-Low, but we made 1000 pointings for each of the modules.

Figures 3 and 4 present the results of Figures 1 and 2 in the form of SPITE, the percentage error expected at each wavelength as a result of random pointing offsets. The primary effect of SPIT is to warp the shape of the spectrum. The problem is more severe in the shorter wavelength modules, where a given pointing error is a larger fraction of the the slit size, and it's worse when using HP2 peak-up.

Table 2 summarizes the maximum errors generated by SPITE for each module and both pointings in the 1-σ and 2-σ positions in the distribution.

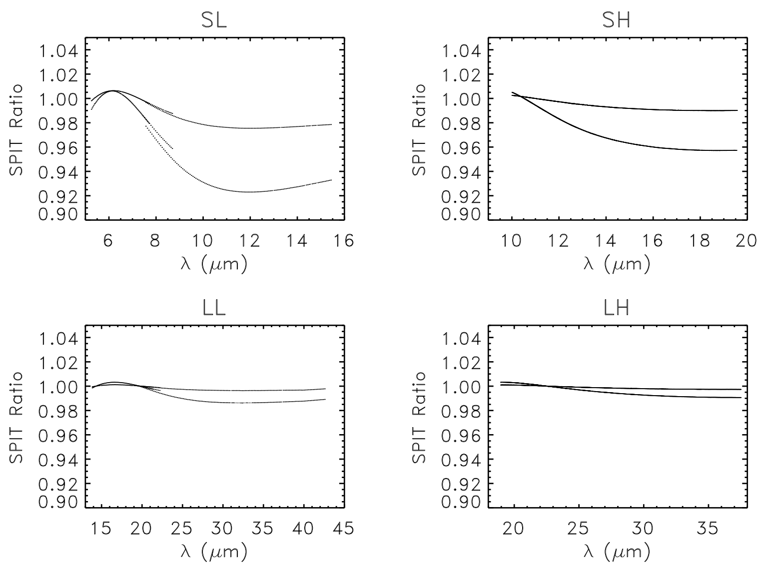

Figure 1 The resultant spectra for 1-σ and 2-σ pointings when using high-accuracy peak-up (HP1) for each module. The spectral throughput for both positions is plotted as a ratio to the throughput of a centered spectrum (SPIT ratio), illustrating how a spectrum can be warped for expected pointing errors. The 1-σ position corresponds to an 0.38 arcsecond offset in the cross-dispersion direction when using HP1.

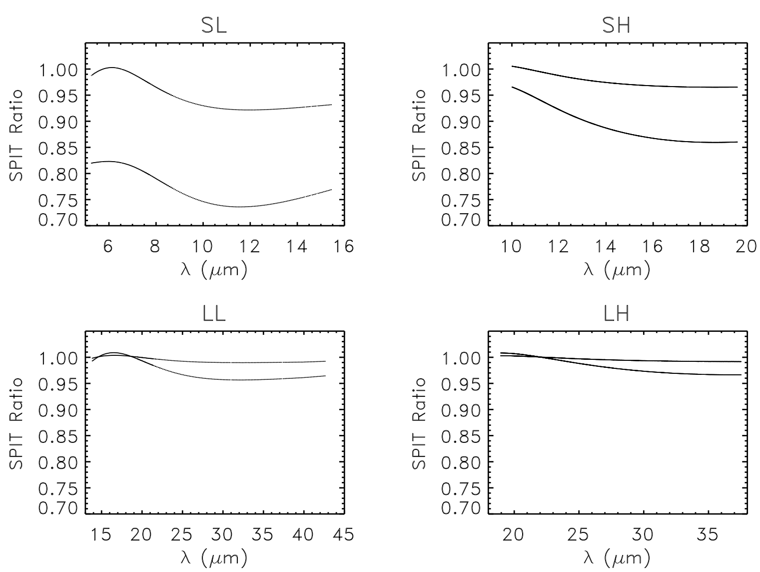

Figure 2 As Fig. 1, except for HP2. A typical 1-σ offset would be 0.71 arcseconds in the cross-dispersion direction.

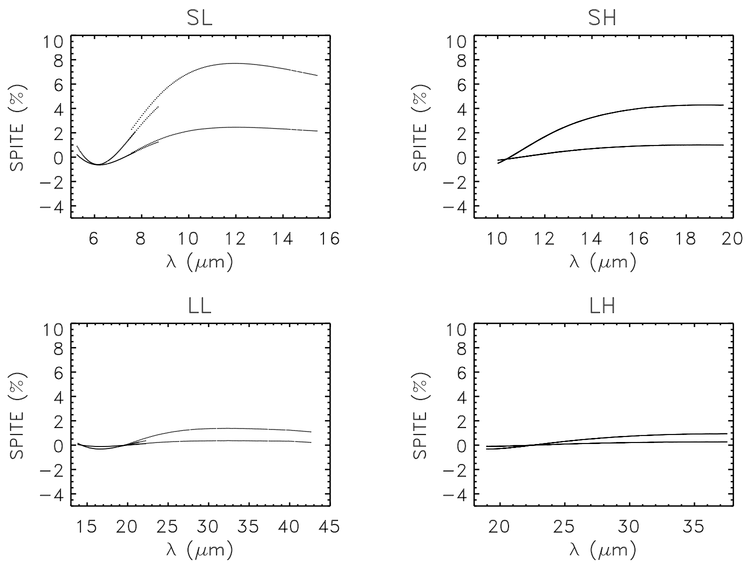

Figure 3 Expected SPITE for HP1 observations with 1-σ and 2-σ offset errors. This figure presents the same information in Fig. 1, except now plotted as a percentage error.

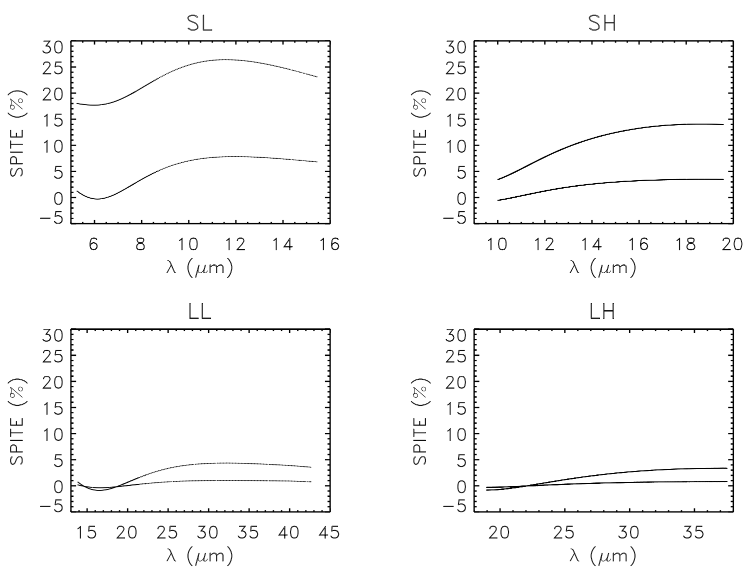

Figure 4 As Fig. 3, except for HP2 observations.

Table 2
Maximum SPITE (%)

Pointing	Module			
	SL	SH	LL	LH
HP1 1-σ	2.5	0.4	0.1	0.3
HP1 2-σ	7.7	4.3	1.4	0.9
HP2 1-σ	7.8	3.5	1.0	0.8
HP2 2-σ	26.4	14.1	4.4	3.4

4 Discussion

For HP1 observations, SL is the only module where we can expect to see noticeable changes in the shape of the spectrum as a result of SPITE. One third of the observations will show errors of 2.5% or more. For the other modules, all of the 1-σ results are under 0.5%. Looking at the 2-σ results reveals that in one observation in twenty, the spectra will show more noticeable artifacts generated by SPITE. In SL, the errors are as bad as 7.7% at $\sim$12 μm, but the errors at $\sim$6 μm remain near zero, resulting in a broad emission artifact if uncorrected. SH also can produce a general warpage in the spectrum as bad as 4.3% in the 18–20 μm range.

Predictably, the HP2 observations are significantly worse. At 1-σ offsets, LL and LH only produce errors of 1% or better, but SH has an error of 3.5% and SL has a more substantial 7.8% error. The 2-σ results show how bad the occasional pointing can be.

There is no avoiding the conclusion that observations of point sources using SL and SH should use high-accuracy peak-up (HP1) if our 5% radiometric requirement is to be met. On the other hand, it appears that moderate-accuracy peak-up (HP2) will produce suitable spectra most of the time for LL an LH.

4.1 Impact on Science

The impact that spectral pointing-induced throughput errors will have on IRS data depends on the nature of the source and the objective of the observer. In the extreme case of an infinitely extended uniform source, for example, SPITE will not affect the data directly. However, it will have an indirect effect as it might warp the shape of the spectrophotometric correction, which is based on observations of a point source.

Observers concerned only with isolated band strengths and shapes need to be concerned with SPITE less than those interested in atomic line ratios from unresolved sources separated by significant wavelength ranges. Atomic lines from different slits, or even from two ends of the same slit may need to be corrected for SPITE before the ratios are within the error budget.

The most alarming aspect of SPITE can be seen in Fig. 1 in the lower curve for SL. The 2-σ curve mimics what an unsuspecting observer might take to be an identified solid state feature at with a strength of 8% of the continuum peaking at 6.0 μm and extending out to nearly 10 μm.

4.2 Correcting for SPITE

There are two possible means of correcting for spectral pointing-induced throughput errors in spectra.

If the nature of the input spectrum is known (for example, with an observation of a standard star), then one could work backwards by taking the ratio of the observed spectrum to the expected spectrum, and comparing the overall shape with that expected for various offsets. While it is possible that some unexpected deviation in the observed spectrum from what is expected could mimic an offset from the center of the slit, the most likely deviations from assumed spectra (either dust excesses or unusually strong or weak molecular bands) will not do this.

Another possibility would be to estimate the SPITE by using the reconstructed pointing data from the pipeline, which will be provided as part of the pipeline output. If the reconstructed pointing is of sufficient accuracy, one could generate the corresponding SPIT correction for the offsets at which a spectrum was actually obtained and correct the spectrum. It would be worthwhile to check to see if this method works by using the spectra of standard stars obtained in IOC activities IRS-090 and IRS-191.

In short, both methods of correcting for SPITE should work, especially if we are able to actually map the effects of SPITE in IOC/SV by shifting a target across the slit. This will allow us to understand how the differences between our assumed PSF and the actual PSF impact our estimates of SPITE.

References

Schroeder, D.J. 1987, *Astronomical Optics* (San Diego: Academic Press)