Optimal Point-Source Extraction for *Spitzer* IRS Spectra

Robert Narron, Patrick Ogle, Russ R. Laher

Spitzer Science Center, California Institute of Technology, Pasadena, CA, USA

Abstract. A new optimal-extraction technique has been developed for deriving point-source spectra from data taken by the Infrared Spectrograph (IRS) on-board the *Spitzer Space Telescope*. The new technique gives improvements of up to a factor of two in the signal-to-noise ratio (S/N) for faint (< 10 mJy) sources, corresponding to an effective quadrupling of the exposure time. Regular extraction consists of an even-weighted summing of pixel values at the same wavelength. Optimal extraction weights each pixel by its S/N, estimated using the spatial profile of a bright calibration star and data uncertainties. Additionally, the optimal-extraction calculations are performed in "rectified" space, and so a natural by-product of the processing is a useful output file containing the rectified image. The optimal-extraction technique is unsuitable for extended sources and best only for point sources.

1. Introduction

At the *Spitzer* Science Center (SSC), we have recently implemented a new capability in our Spice[1] (Spitzer IRS Custom Extraction) software, which allows the astronomer-user additional flexibility in extracting a spectrum from data acquired by the Infrared Spectrograph (IRS) on-board the *Spitzer Space Telescope*. The new capability, called *optimal extraction*, is described in this paper.

2. Optimal Extraction

With Spice software version 1.4.1 (and higher), the user has the new option of selecting profile-weighted/signal-to-noise-weighted "Optimal" extraction (in the `Type` pull-down menu under the `Extract` tab). The default is unweighted "Regular" extraction. The output table filename is the same, regardless of which option is chosen, and table-header information gives the extraction type.

Optimal extraction, as currently implemented in Spice, is a modified version of the formulation of Horne (1986). It yields a minimal-noise, unbiased flux estimate in each wavelength bin by weighting the extraction by the object profile and the signal-to-noise of each pixel. Specifically, the flux density (electrons s^{-1}) in a wavelength bin, F, is given by:

$$F_i = \frac{\sum W_i F_i / P_i}{\sum W_i},$$

(1)

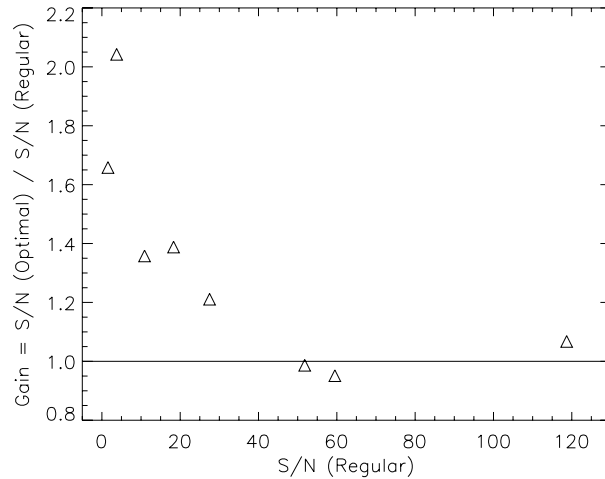[1]http://ssc.spitzer.caltech.edu/postbcd/spice.html

Figure 1.   Gain factor for optimal extraction over regular extraction as a function of regular S/N for the standard extraction apertures, derived from SL and LL observations.

where W_i is the weight:

$$W_i = (P_i/\sigma_i)^2 \qquad (2)$$

F_i the flux, P_i the stellar profile template, and σ_i the uncertainty in the ith pixel.

Our modification of Horne's algorithm is to use a stellar profile template from a calibration-standard star, rather than estimating from the science target itself an instrumental profile that is smoothed in wavelength. The advantage of our approach is that it gives much greater S/N for the instrumental profile than the typical science target. This is practical for space-based observations with an instrument that has an unchanging point-spread function (PSF), whereas from the ground, atmospheric seeing makes the PSF highly variable. Also, because of PSF under-sampling by the *Spitzer* IRS instrument, the template has a lot of substructure in the wavelength direction, and so it does not work to smooth the instrumental profile over wavelengths.

Optimal extraction provides greater improvement over regular extraction for low S/N data. Figure 1 shows the gain in optimal S/N versus regular S/N. Gains in S/N up to a factor of 2 have been achieved for sources with $S/N \sim 3$, corresponding to an effective quadrupling of the exposure time. There are diminishing returns for sources with $S/N > 30$. Comparable gains in S/N have been achieved by narrowing the extraction aperture to ~ 3 pixels and performing a regular extraction. However, regular extraction with a small aperture requires custom flux calibration, and yields somewhat lower S/N.

No special steps are required prior to optimal extraction; execute `Profile` and then `Ridge` the same as you normally would in Spice before the extraction step. Note that optimal extraction is more sensitive to the ridge location than regular extraction. For faint sources where the profile is noisy, the Ridge percentage can be refined manually until the best result is obtained. Figure 2 shows
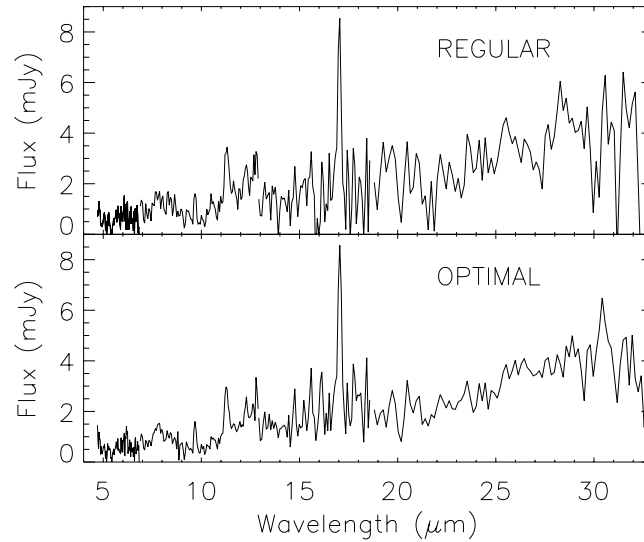
Figure 2.   Comparison between spectra extracted using the regular and optimal methods from the same input data.

a comparison between spectra extracted from the same data using regular and optimal methods.

Optimal extraction is accomplished as follows by the `optimum` module. First, the dispersed image of the source is divided by the dispersed image of a calibration-standard stellar point source. At each wavelength, the flux of the calibration-standard template is normalized to unity, and the peak is shifted to the center of the extraction window. Next, each pixel in the aperture is weighted by $(S/N)^2$, and the weighted average flux is computed.

By default, the input uncertainty file (specified in Spice's `Input` tab) and a calibration-standard point-source profile are used to compute the weights and output uncertainties. Alternatively, the user can enter a constant uncertainty value (in electrons s^{-1}), which will give a purely profile-weighted extraction. This option is appropriate for sources that are fainter than the background and where background noise dominates, or if the uncertainty file is noisy. The output uncertainties will reflect whatever constant is specified by the user, rather than the true uncertainty.

To facilitate alignment of the source to the calibration-standard profile, optimal extraction is performed in rectified space. The curved basic-calibrated-data (BCD) image is straightened using the `wavsamp.tbl` calibration file. Because the PSF of the Spitzer IRS is under-sampled and the spectral trace does not follow columns exactly, diagonal stripes are visible in the rectified spectral images. Each order is rebinned during the rectification to 1001 pixels in the spatial direction, in order to increase the accuracy of the rectification and avoid pixelization errors at the edges of the aperture. Unweighted extractions in rectified space match regular extraction to better than 1%.

Rectified flux, uncertainty, and *bmask* products are written out by the `optimum` module, allowing the user to inspect the spatial profile of the source

or construct custom profile templates. The latter can be done via optimal extraction of a bright star observed at the same ridge percentage as the science target. The rectified 2-D stellar spectrum from `optimum` will be the custom profile template.

The rectified stellar templates used for point-source profiles are provided in Spice's "cal" directory. A template is supplied for each channel, order, and standard nod position (including nod 1, nod 2, and slit center) with filenames like `b[channel]_rectempl_[order][nod].fits`. These were constructed with *Spitzer* IRS observations of the flux calibration standards HR 7341 (1 Jy at 12 μm; SL and LL) and ξ Draconis (11 Jy at 12 μm; SH and LH). `Optimum` will automatically select the appropriate template for the channel and order, the one closest to the selected ridge location. Sources in the non-commanded order can be extracted using the `Orders` pull-down menu under the EXTRACT tab.

Optimal extraction works best for *point sources* observed in IRS Staring mode, at the standard nod positions (33%, 66%) or at the center position (50%). For sources observed at the non-standard locations along the slit, `optimum` will choose the closest stellar template, in terms of the ridge percentage. However, low-frequency sinusoidal wiggles may appear in optimally-extracted spectra if there is a mis-match with the stellar template.

3.   Conclusions

We have described various aspects of our implementation of optimal extraction in version 1.4.1 of the Spitzer-Science-Center's Spice software. The main benefit of this new capability is improved signal-to-noise ratio.

Optimal extraction of extended sources has not been tested. If a calibration-standard point source profile is used, the center of the object will be weighted more than the outskirts. An extended source profile could be constructed, but it must incorporate pixelization effects and have an S/N greater than that of the spectrum to be extracted, in order to achieve any gain. Spice users should not tune optimally-extracted spectra with the extended-source flux calibration. Spice's `ExtSrc Tune` function assumes the science target uniformly fills the slit, whereas optimal extraction assumes a point-source cross-dispersion profile.

References

Horne, K. 1986, PASP, 98, 609