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IRS-TR 04004: The Slope-Fitting Problem in the Data Reduction Pipeline

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Abstract

We report on the discovery and diagnosis of the slope-fitting error in the data reduction pipeline. This error has now been repaired, but its effect is present in earlier pipeline versions, where it may be the dominant contributor to large discontinuities between spectral segments.

1 Introduction

Soon after the launch of the Spitzer Space Telescope it became apparent that the IRS was suffering from substantial discontinuities in the flux at the boundaries between spectral segments. At their worst, the discontinuities could be ∼50%, and the worst discontinuities tended to appear between modules, as opposed to between orders within a given module.

Sloan (2004, IRS-TR 04002) conducted an initial assessment of the discontinuities between Short-Low order 1 (SL1) and Long-Low order 2 (LL2) at 14 μm using a large sample of data obtained for spectrophotometric calibration. Three of the standards examined were galaxies, and since the rest were stars, only these three had spectra increasing in strength to the red. Two of the three galaxies

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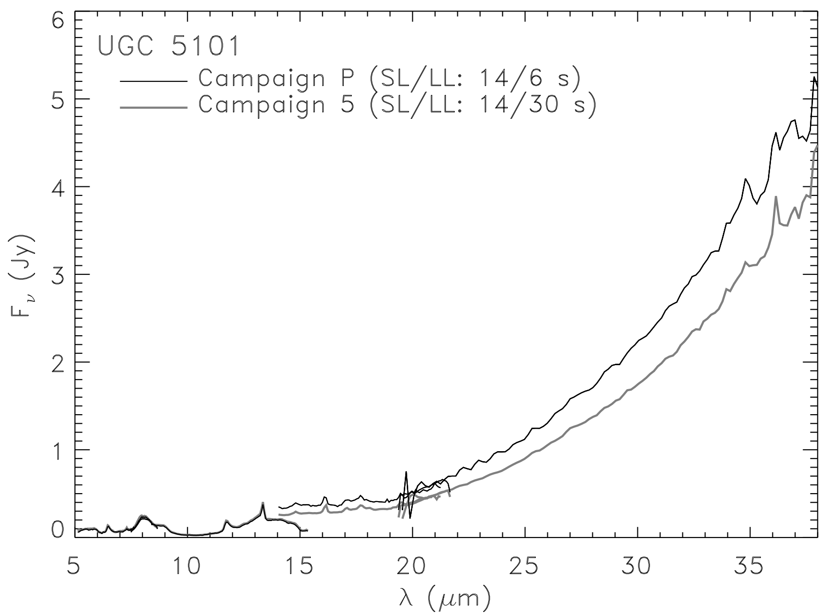

Figure 1 —A comparison of the low-resolution spectra of UGC 5101 obtained in Campaign P (2003 November, thin black lines) and Campaign 5 (2004 March, thick gray lines). The change in ramp times for LL has resulted in a 26% drop in apparent flux in that module.

showed the worst discontinuities in the sample. Expressed as the ratio of fluxes SL1/LL2, these were 0.58 and 0.72, for UGC 5101 and Mrk 279, respectively. The other galaxy, IRAS 07598+6508 showed a smaller discontinuity, 0.88.

The one known cause of discontinuities prior to launch was the dependence in how much light from a source gets through the spectroscopic slit with the position of the source in the slit. Random pointing errors will result in some observations being well centered in the slit and some more poorly centered, and it results in what we call spectral pointing-induced throughput error, or SPITE. The pointing behavior of the telescope rarely produces offsets as large as an arcsecond, and even in the narrowest slit, SL, which is most sensitive to SPITE, these offsets would only produce errors of $\sim$15%, which are much too small to explain the discontinuities observed in some sources.

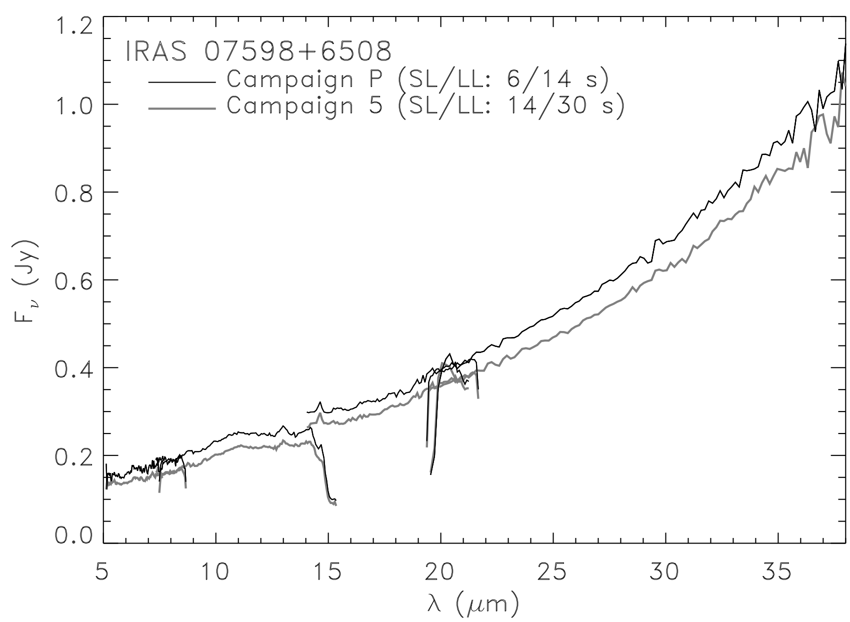

Figure 2 —A comparison of low-resolution spectra of IRAS 07598+6508 as observed in Campaigns P and 5 (thin black and thick grey lines, respectively). The increase in ramp times in SL and LL have resulted in apparent decreases in flux of 14% and 11%, respectively.

2 Diagnosis

The key clue to the cause of the largest discontinuities in the IRS spectra came on 15 April, when Cornell began to compare observations of UGC 5101 taken during the Science Verification phase (SV) of the mission (Campaign P, 2003 November) with observations of the same source taken in normal operations (Campaign 5, 2004 March). Figure 1 compares the two spectra. Both have been processed using version 9.5 of the online pipeline at the Spitzer Science Center (SSC) and the technique described in IRS-TR 04002. In this spectrum, the SL segments are fairly similar, but the strength of the LL spectrum has decreased from Campaign P t Campaign 5. Specifically, the ratio of the SL spectra, measured in SL1 from 11.0 to 13.0 μm, is 0.94 (Camp. P / Camp. 5). The corresponding ratio for LL1 (24.0–28.0 μm) is 1.26. The only difference between the two sets of observations was the ramp time used for LL. In Campaign P, we observed UGC 5101 with 6-second ramps, while in Campaign 5, we used 30-second ramps.

Analysis of IRAS 07598+6508, which was also observed in Campaigns P and 5, shows similar results (Figure 2). While the discontinuity in LL is smaller than for UGC 5101, the discontinuity in SL is more noticeable. The ratios in flux, as defined above for UGC 5101, are 1.14 for SL and 1.11 for LL. From Campaign P to Campaign 5, the ramp times for both modules increased, from 6 to 14 seconds for SL, and from 14 to 30 seconds to LL.

Figure 3 investigates the effect of ramp time on the entire sample of spectrophotometric calibration observations through Campaign 3 by using different plotting symbols for the ramp times in LL when plotting the strength of the discontinuity as a function of overal flux in LL2. Fluxes are measured in both modules by averaging the spectra between 14.0 and 14.3 μ. The discontinuity is quantified as the ratio of flux in SL1 over LL2. When the LL ramp time was 120 seconds, the SL ramp time was 14 seconds; in most other cases, the SL ramp time was 6 seconds.

When the flux in LL2 is greater than 0.65 Jy, the differing LL ramps clearly divide the region into two. From 0.65 Jy down to 0.35 Jy, all of the data were obtained with 30-second LL ramps, so no judgement can be made here. In the region from 0.35 Jy down to 0.15 Jy, all four LL ramp times were used, and the mean discontinuity for each ramp time moving monotonically as the ramp time increases from 0.58 (UGC 5101, discussed above) for a 6-second ramp to 1.0 or greater for a 120-second ramp. Below 0.15 Jy in LL2, the data were all observed with the same ramp time.

The ramps with integration times of 6, 14, and 30 seconds have 4, 8, and 16

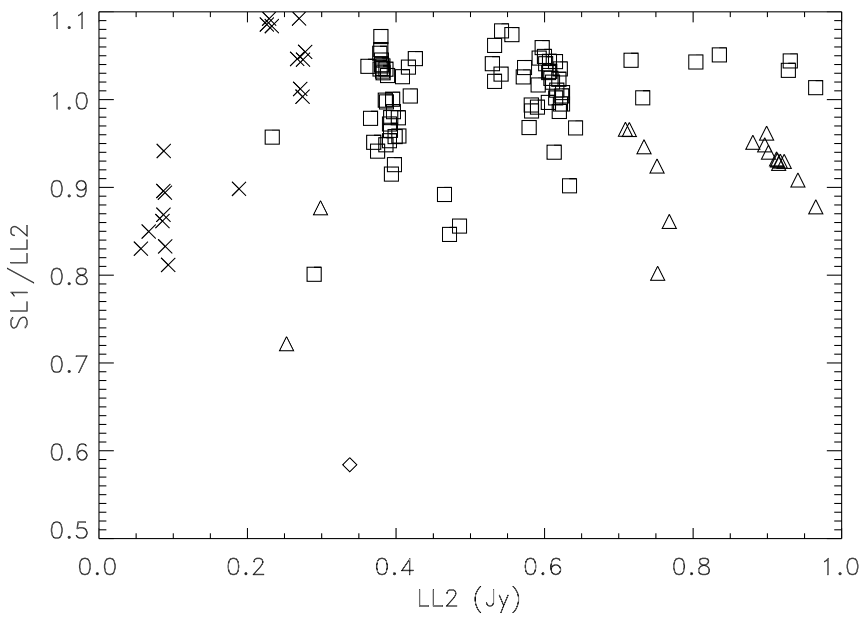

Figure 3 —The strength of the discontinuity as a function of overall flux, with different plotting symbols used to distinguish between LL ramp times: 6 sec - diamonds, 14 sec - triangles, 30 sec - rectangles, 120 sec - crosses. This plot is an analog to Figures 2 and 3 in IRS-TR 04002, where symbols distinguished peak-up method and source type and no trends were apparent. Here, segregating by ramp times seperates the data in the region where flux in LL2 is greater than 0.65 Jy, and in the region around 0.15–0.35 Jy.

samples between resets, respectively. Longer ramps have the same number of samples, but have longer intervals between samples.

Within a week of our initial clue, the problem was tracked to how the data reduction pipeline used by the SSC assigned a slope to a given ramp. We took a data cube with 16-sample ramps (128×128×16) and fitted a slope to it using (1) the Cornell Pipeline Interactive Reduction and Analysis Tool (PIRAT) and (2) the offline pipeline (version 9.5) supplied by the SSC to Cornell. PIRAT served as a control to the SSC pipeline. The test image was one of the LL1 observations of UGC 5101. In both cases, we fit the first 4 samples of each ramp and then all 16 samples. Figure 4 compares the PIRAT results for the shortened and full ramps. The ratio between the slopes is nearly one where the signal is large enough to suffer little from noise but not so large that nonlinearities begin to affect the slope. A result near one is expected for most slopes, since the slope should not change from the first four samples to the last sample. Figure 5 compares the results of the SSC pipeline, and here the results for shortened and full ramps are surprisingly different. The ratio of the slope from the four-sample ramp to the 16-sample ramp is between 1.3 and 1.35 for most of the brighter ramps. This experiment showed that the SSC pipeline had a systematic problem in how it fit slopes to ramps of different lengths.

This problem occurs in the *imagest* module in the pipeline. This module shares software developed for MIPS, where one should divide a ramp by the number of samples to determine its slope. For the IRS, however, one should divide by the number of intervals, which is always one less than the number of samples.

3 Consequences

Thus, for a ramp with N samples, the error in slope is $N/(N-1)$. The dominant component of this error will be a scalar, so the apparent fluxes at all wavelengths obtained with a given ramp time should be affected identically.

The slope-fitting problem can be mitigated when calibrating a spectrum by dividing by a spectrum of a standard star. As long as the science target and standard star have the same ramp times, the slope-fitting problem will cancel out. Standard stars recommended by Cornell for use as calibrators have all been observed with 6-second ramps in SL and 30-second ramps in the other modules. Because all ramps longer than 30 seconds still have 16 samples, they can be properly calibrated with stars observed with 30-second ramps. Thus all spectra calibrated with recommended standards will be correct if observed with 6-second ramps in SL or

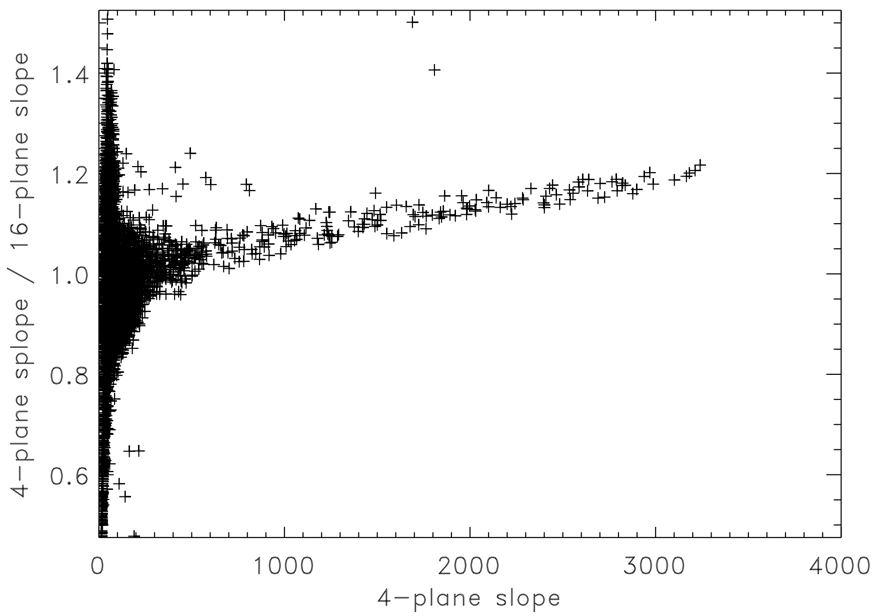

Figure 4 —The ratio of slopes fi t by PIRAT to the signal ramps for 4-plane and 16-plane ramps as a function of slope (signal). Most of the ratios are close to one, but the noise dominates the results for the faintest signals, and for the brightest signals, nonlinearities are pulling the ratio away from unity.

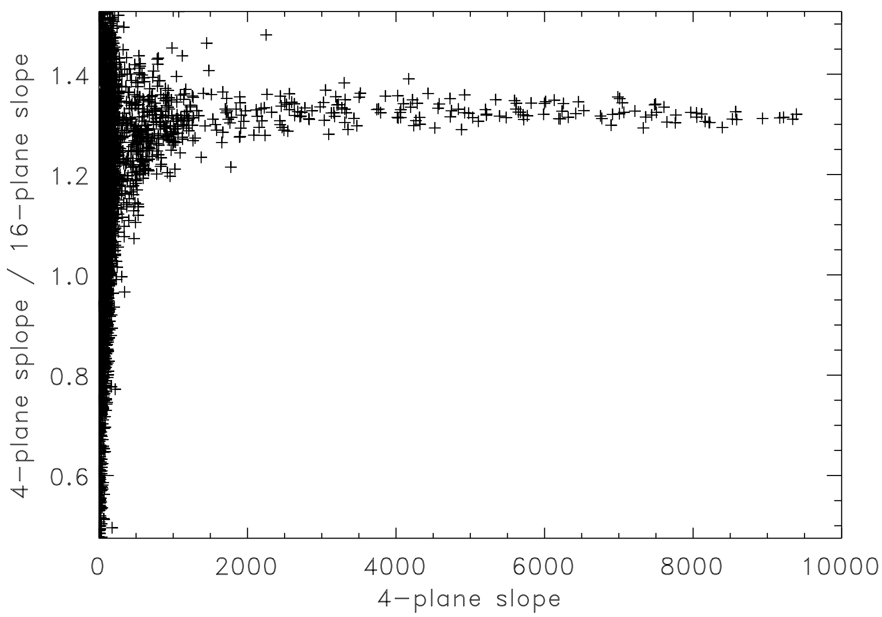

Figure 5 —As Fig. 4, but for the slopes as fi t by the offline pipeline. Here, the ratio of the slopes is consistently greater than 1.3, indicating a problem with the slope-fi tting algorithm in the data reduction pipeline.

TABLE 1
ERRORS FROM SLOPE-FITTING

Ramp time of calibrator (s)	Number of samples	Ramp time of science target 6 s	14 s	30+ s
uncalibrated		1.333	1.143	1.067
6 s	4	1.000	0.857	0.800
14 s	8	1.167	1.000	0.933
30+ s	16	1.250	1.071	1.000

30-second or longer ramps in the other modules.

Table 1 gives the errors caused by the slope-fitting problem, and it shows how this error propagates when dividing by the spectrum of a calibrator. To correct a spectrum, one should locate the appropriate entry and divide the spectrum by the number in the table. For UGC 5101, both SL spectra require no correction, since both target and standard were observed with 6-second ramps. The ratio of the two SL spectra of 0.94 probably arises from pointing errors and SPITE. For the UGC 5101 LL spectra, the Campaign 5 data require no correction, but the Campaign P data, observed with a 6-second ramp and calibrated with a 30-second ramp, need to be divided by 1.25. The observed ratio is 1.26, which agrees closely. In the spectrum of IRAS 07598, we would expect the SL spectra to be correct in Campaign P and too low by a factor of 0.857 in Campaign 5. The ratio of the spectra would be 1.167, and again, this is close to he observed 1.14. For IRAS 07598 in LL, Campaign P would be too high by 1.071, and Campaign 5 would be correct, giving a ratio of 1.071 compared to 1.11 as observed. These values are close, but the 4% difference suggests another problem is contributing.

4 Prognosis

The slope-fitting problem existed in all versions of the SSC pipeline through 10.5, which processed all data delivered by the SSC through 2004 July. The new version of the pipeline, tentatively known as Version 10.5 Proc. A and used starting in 2004 August, has fixed the problem.

It is important to note, however, that this repair will not eliminate the largest discontinuities in the spectra, which are greater than 33% and so must arise at least in part from some other cause. The combination of repairing the slope-fitting error and correcting for SPITE, which could contribute another 10–15%, or more in worse cases, should go a long way, though, in reducing the discontinuities seen in IRS spectra.

5 Lessons Learned

The slope-fitting problem came to light in the preparations for the commissioning of the SSC Data Archive and not months earlier during the In-Orbit Checkout (IOC) and SV phases of the mission, as one would have hoped. In hindsight, there were many clues that a problem existed, mostly from the spectrophotometric calibration program. The star ξ Dra provides the best example. It was observed with a 6-second ramp in LL and a 60-second ramp in LH. Its calibration in LH was consistent with other sources, but in LL, it was too bright by 25%. Given the many difficulties with flatfielding, extraction, and calibration early in the mission, the significance of the differing ramp times in ξ Dra was not apparent because the ramp times applied to different modules. It was not until we compared observations of the same source in the same module with different ramp times that the problem became obvious. It is unfortunate that we did attempt this experiment during IOC or SV. Hopefully, future space telescope missions will not repeat this error.

References

Sloan, G.C., IRS-TR 04002: Discontinuities between the Low-Resolution Modules on the IRS