

Update to IRS Short-Lo Frame Table Entries

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Abstract

We propose updates to the Spitzer onboard frame table entries for the IRS Short-Lo slits. These updates are based on measurements made independently by the IRS IST and Cornell ISC, and are consistent with predictions based on an improved understanding of spacecraft gyro calibration. The maximum correction is just under half an arcsecond for the SL1, 1st dither position. The proposed frame table modifications would increase the average throughput by 5% in SL1-1 and 3% in SL1-2. In addition to increasing throughput, improving pointing knowledge, and reducing sensitivity to random pointing errors, this would also reduce by at least half the known discrepancy between standard star measurements taken at the two SL1 dither positions. However, it is not expected to help significantly with the 4% discrepancy between the two SL2 dither positions.

1. Background

Focal Plane Mapping (FPM) was conducted over the course of three IOC campaigns. Based on a priori estimates of various uncertainties in our measurements and in the pointing control system, the Spitzer Space Telescope Focal Plane Survey Final Report (JPL D-27667, 8 July 2004) estimated final uncertainties in our knowledge of the SL slit location of better than 0.12 arcseconds. This is to be compared with the pre-launch knowledge requirement of 0.14 arcseconds.

During Nominal Operations, certain idiosyncrasies in the pointing control system became apparent, particularly in the calibration of the gyros. This was best illustrated by the IRS Large Offset Test, which revealed that simply hopping back and forth between two stars separated by 30 arcminutes led to a wandering of the telescope away from the commanded pointing by 15 to 30 arcseconds in less than half an hour. Being much larger than the dimensions of the IRS slits, this was clearly unacceptable, and steps were taken to place greater emphasis on the star tracker in our AOT commanding structure, and less reliance on the gyros.

2. Hypothesis

Reflecting on our hard-won knowledge of gyro calibration and performance, we considered whether our focal plane mapping strategy during IOC could have been partly undone by inaccurate calibration of the gyro scale factors. During IOC, we mapped the IRS portion of the focal plane by using the gyros to scan the telescope back and forth across a particular target and looking at the peak flux as a function of time to tell us

precisely when we'd crossed the middle of the slit. During this exercise, OET provided the pointing reconstruction as a function of time. PCRS centroids were taken before and after every iteration (roughly 500 seconds in length), and any shift in the observed centroids was attributed to gyro drift and modeled out of the final, position-vs-time table transmitted to David Bayard and the JPL FPM team.

If the gyros had suffered from the scale factor error similar in magnitude to what we saw during the IRS large offset tests, both the pointing and the pointing reconstruction during IOC FPM would have been compromised to some extent. While OET did their best to take out the gyro bias, they did not know about a possible scale factor problem at the time. If indeed we had an error of the type we saw in the IRS large offset tests, rather than moving across the slit in the intended rectilinear fashion, the pointing control system could have skewed the pattern in one direction or the other.

The scans across the slits lasted between 40 and 60 seconds, or about the same amount of time as a 1 degree slew (though the scan lengths were typically more like 40 to 140 arcseconds). While we scanned back and forth across the slit to take out possible systematics, we unfortunately always started from the same end of the slit. If the telescope was scanning faster (or moving farther) in one direction than the other due to a scale factor error, the difference between the requested and true position of the telescope would be a function of scan distance. However, this offset was interpreted solely as gyro drift (a function of time), then correcting for this drift would skew the reconstructed coordinates even more in the opposite direction.

Figure 1 shows a typical FPM iteration in which we've imposed a gyro calibration scale which is 0.07% larger in the +X direction than in the -X direction (consistent in magnitude with our IRS large offset tests). We do a PCRS centroid determination at X,Y=-1000,-1000, put the target at the upper end of the slit, scan back and forth a few times along the slit, and finally return to X,Y=-1000,-1000 to get another PCRS centroid. This sequence is shown by the filled circles (note that the X axis is greatly expanded compared with the Y). Because of the difference in +X,-X scale factors, we don't return to the original PCRS location, but rather about 0.8 arcseconds to the right of it. If we now attribute this 0.8 arcseconds wholly to gyro drift and correct all intervening points using a drift magnitude of 0.0018 arcseconds/second in the X direction, we end up with the open circles. So while the scale factor error has pushed the scan pattern at the bottom end of the slit a little to the right of vertical, inappropriately correcting for gyro drift puts the lower end of the scan pattern to the left of vertical. For a 0.07% difference in scale factor, the numbers for this Short-Lo slit analog work out to be a 0.3 degree error in orientation angle, and a 0.6 arcsecond systematic, single axis centroiding error at the lower end of the slit. This number is considerably larger than the FPM requirement of 0.14 arcsec radial.

This model has been outlined and discussed with Dan Swanson (formerly of OET) and David Bayard, both of whom have concurred with its plausibility and magnitude. Swanson designed and carried out the pointing reconstruction procedures above during the IOC focal plane mapping campaigns. Bayard and his team developed and ran the

code which converted inputs from OET and the IRS team into useable frame table entries.

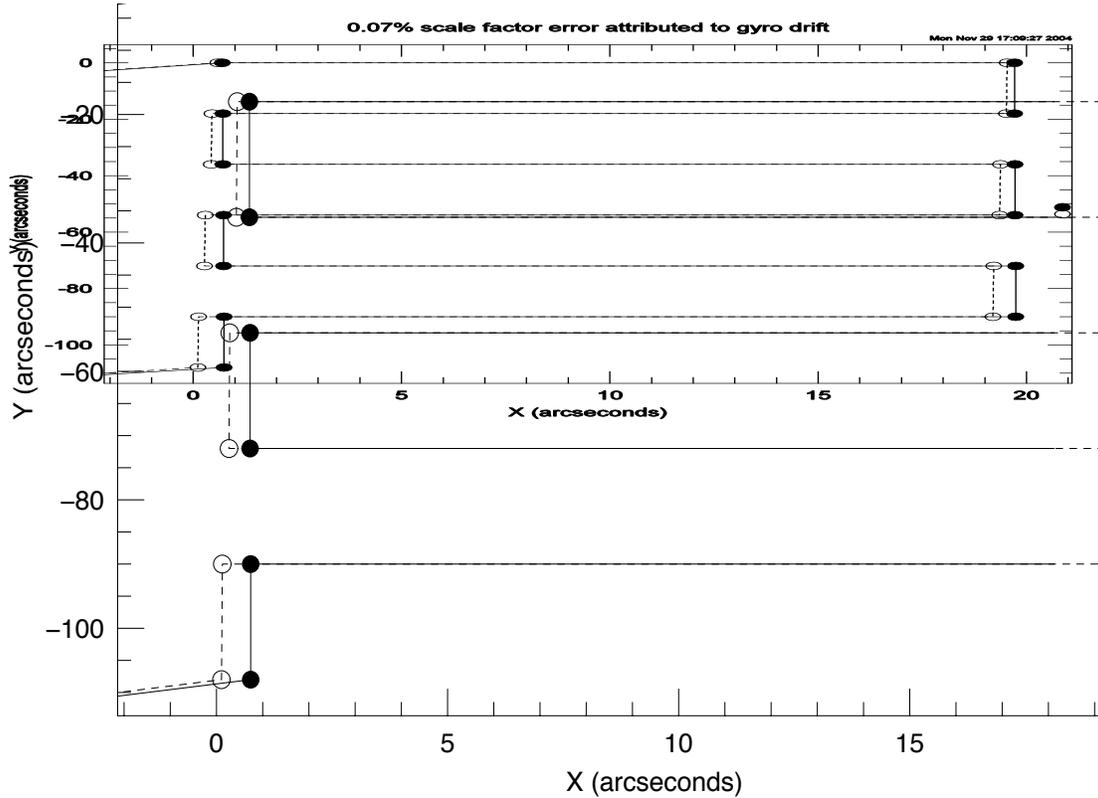


Figure 1

3. Data

Based on our concerns above, we obtained approval from the SSC Director to carry out experiments during IRS campaigns 18, 20, and 21 to check the accuracy of the IRS slit positions. To avoid possible issues with gyro calibration and take advantage of the better pointing stability to be had with the star tracker, we did not employ the scanning IERs used during FPM, but used standard IRS Mapping AORs instead. This also ensured that we were testing the pointing system in a mode identical to that used for science observations. The AORs employed 7x7 maps, with 0.75 arcsecond steps perpendicular to the slits, and 9.5 arcseconds steps parallel, for both SL1 and SL2. All AORs were preceded by a high accuracy IRS peak-up. The disadvantage of these AORs was that they were comparatively inefficient, and only a limited amount of data could be obtained in a reasonable allocation of time. Three stars (HD 173511, HR 6348, and HD 115136) were mapped in SL in each of IRS campaigns 18 and 20.

Figure 2 shows the offsets from slit center measured as a function of distance from the outboard end of SL2. SL2 thus occupies the region from 0 to 57 arcseconds, and SL1 occupies the region from 79 to 136 arcseconds. The offsets were determined by measuring the total flux within 2 pixel columns of the centroid of each map leg on the array, and plotting this flux against commanded offset position. We fitted Gaussians to the run of total flux versus position and used the position of the peak of the Gaussian to define the point at which the star would have been centered in the slit. If the frame table had been perfect, the peak flux would always have occurred at the fourth step of each map leg. The offsets shown in Figure 2 give a measure of the difference in arcseconds between the fourth mapping step and the predicted position of maximum throughput. A perfect frame table would therefore yield a mean offset of 0 arcsec. Filled and open circles correspond to HD 173511, filled and open squares correspond to HR 6348, and filled and open triangles denote HD 115136.

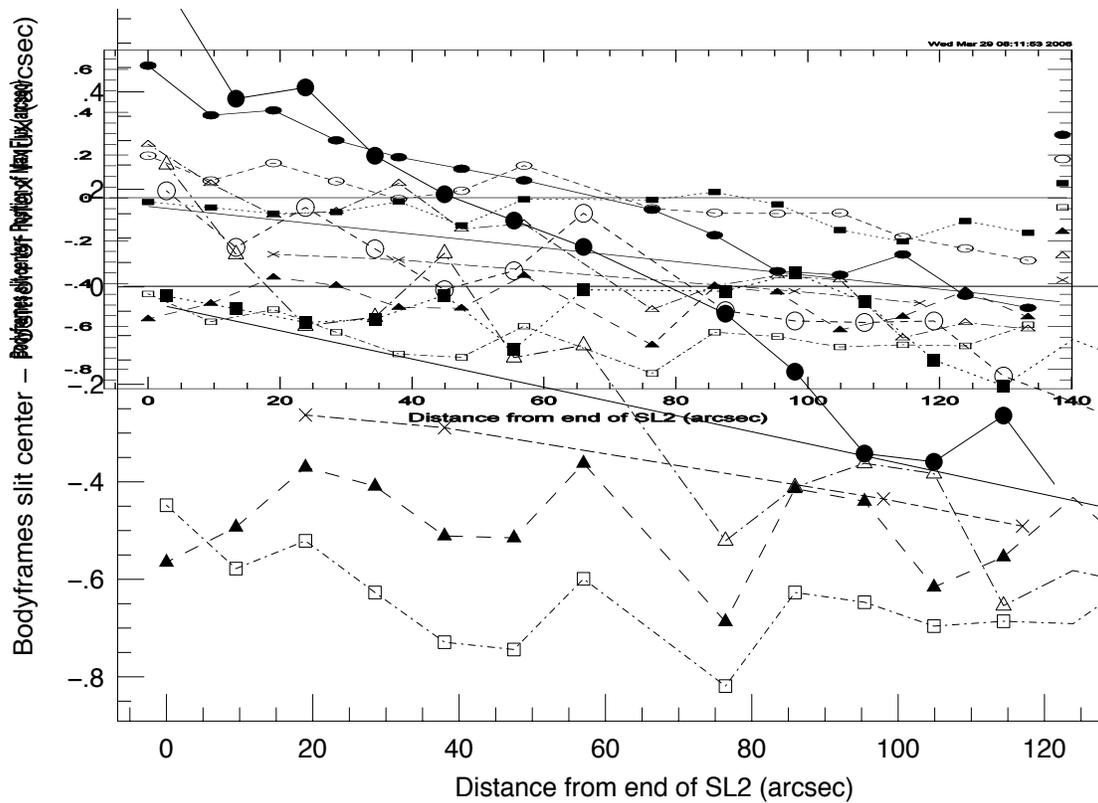


Figure 2.

Also shown in Figure 2 are results from the Cornell Doublestar experiments, taken during a similar period of time ("x" symbols). These tests mapped across the SL1 and SL2 1st and 2nd dither positions with 0.2 arcsecond steps, while simultaneously monitoring the motion of a second star situated in the peak-up array. This enabled the measurement and removal of random pointing errors as well as more finely sampling and centroiding the

point spread function. Figure 3 shows the throughput as a function of the commanded offset from slit center for a single mapping leg across the 1st dither position of the SL1 slit. The “plus” signs show the commanded positions while the open diamonds show the actual throughput (where the center of the slit is defined by the point of maximum throughput).

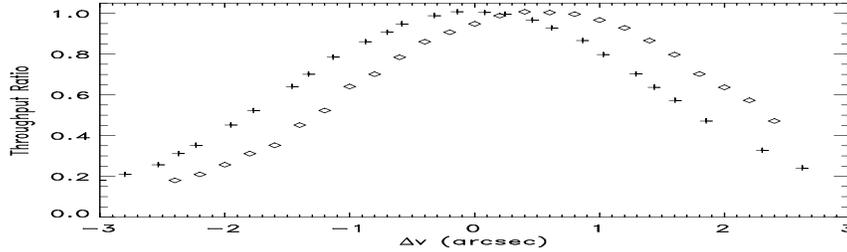


Figure 3.

4. Analysis

Several things are apparent in Figure 2. (i) The scatter between observations of different stars, and between the same stars observed in different campaigns, is significant, with $\sigma \sim 0.2$ arcseconds. However, this is accord with expectations for the peak-up centroiding algorithm and the random offset error induced each time the telescope is moved. (ii) The points on the left hand side of the plot (SL2) have an average value near zero, whereas almost all of the points on the right hand side of the plot (SL1) lie below zero. (iii) The fewer but more precisely measured Doublestar points agree very well with the general trend, and fall within the uncertainties of the mean relation.

Fitting all of the data in Figure 2, we obtain the linear relation shown by the solid line. This line corresponds to an error in the orientation or position angle of the SL slit of 0.22 degrees, an offset at the SL2 end of the slit of -0.04 arcsec, and an offset at the SL1 end of the slit of 0.43 arcsec. These numbers are consistent with the predictions of Section 2,

indicating that we very probably did suffer from gyro scale factor errors of the size seen during Nominal Operations.

The offsets are such that the center of the target star prefers to sit on the outboard side of the SL slit. This indicates that we have overestimated the distance between the boresight and the SL slit, and that the magnitudes of θ_y (in particular) and θ_z need to be reduced. Based on this assumption, we have computed the attached table of WAS-IS frame table entries. We propose to modify both the SL1/SL2 frame table positions (θ_y and θ_z) and the slit angles (so that spectral maps are aligned with the slits).

Table 1

	WAS			IS			offset
FOV	θ_y	θ_z	Angle	θ_y	θ_z	Angle	arcsec
SL1-1	26	-12.0475	-2.6312	275.28	-12.0406	-2.6306	275.06 0.414
SL1-2	27	-12.0176	-2.9540	275.28	-12.0117	-2.9535	275.06 0.353
SL1-C	28	-12.0326	-2.7926	275.28	-12.0262	-2.7920	275.06 0.383
SL-C	29	-11.9728	-3.4429	275.28	-11.9685	-3.4425	275.06 0.257
SL2-1	32	-11.9272	-3.9397	275.28	-11.9245	-3.9395	275.06 0.162
SL2-2	33	-11.8989	-4.2466	275.28	-11.8972	-4.2464	275.06 0.101
SL2-C	34	-11.9131	-4.0932	275.28	-11.9109	-4.0930	275.06 0.131

5. Conclusions

Based on the throughput curve shown in Figure 3, we estimate that correcting the frame table as in Table 1 would increase the throughput in SL1 by 5% (1st dither position) and 3% (2nd dither position). This would have the additional benefit of at least halving the current discrepancy in the measured standard star fluxes at the two dither positions. For SL2 this discrepancy is about 4%, but correcting the SL2 frame table entries would recover only a small portion of this since (i) the frame table corrections are smaller, and (ii) the SL2 point spread function is somewhat narrower than at the longer SL1 wavelengths.

In addition to improving net throughput and partially correcting the known throughput discrepancies between dither positions, correcting the frame table would also render the IRS less sensitive to random pointing errors. Owing to the shape of the point spread function, random offset errors of fixed size will render a smaller total fraction of light lost if the mean position of a star is in the center of the slit. For example, at the corrected SL1, 1st dither position, a 0.2 arcsec random pointing error would yield a corresponding throughput diminution of 5% (2 sigma). Left uncorrected, the same pointing error would yield throughput reductions from 5 to 8%.

Of course, updating the frame table is not without consequences for the IRS pipeline. In particular, the pipeline treatment of data would have to be bifurcated on the day that the frame table is updated. Data taken prior to that date would require the use of the current wavesamp and fluxcon files, while data taken after that date would require new flux and wavelength calibrations. This requires little additional effort on the part of the IST, since flux and wavelength calibrations are generated as a matter of routine. Moreover, the bifurcation of the pipeline has already been demonstrated for the Long-hi bias change and found to be straightforward.

We propose to update the frame table on the last day of an IRS campaign, and then to conduct a Doublestar pointing test and any other required calibration exercises which do not require accurate pointing. In this way we can validate the update without risking any science data. Analysis of the Doublestar experiment would be conducted primarily to ensure that the frame table updates were applied in the right direction, rather than to improve our estimate of the slit center position. If our analysis shows that the frame table updates were applied incorrectly, we can make appropriate corrections well in advance of the next IRS campaign.