Wavelength Calibration Accuracy of the First-Order CCD Modes Using the E1 Aperture

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ABSTRACT

A calibration program was carried out to determine the quality of the wavelength calibration for the first-order CCD spectroscopic modes at the E1 pseudo-aperture locations. These apertures have been used since Cycle 10 to mitigate the effects of CCD charge transfer inefficiency. Emission line spectra from the HITM1 wavelength calibration lamp were obtained. This lamp illuminates the CCD near row \( \sim 900 \), where the E1 apertures are located, far better than does the LINE lamp. These data files were reduced using the wavelength calibration files used in the standard CALSTIS pipeline, and the magnitude of the errors was determined. It was found that, within measurement errors, all modes except \( \lambda_c = 7751 \) are within the limits given in the STIS Instrument Handbook, although the calibration is often not as good as in the nominal case using the standard apertures, and it quickly degrades at row numbers greater than 900.

Introduction

The STIS CCD charge transfer inefficiency (CTI) is getting worse with time, due to the accumulated effects of radiation exposure. The consequences of CTI are worse for pixels that require many transfers before reaching the output amplifier of the CCD; that is, at low row numbers. The nominal location of the spectrum when using the \( 52 \times 2, 52 \times 0.5, 52 \times 0.2, 52 \times 0.1, \) and \( 52 \times 0.05 \) apertures is near the center of the chip, row \( \sim 512 \). To mitigate the effects of CTI, starting in Cycle 10 users were encouraged to use the new E1 pseudo-apertures. They place the spectrum approximately at rows 893 – 898, depending on the aperture selected, resulting in far fewer charge transfers.
The wavelength calibrations of the spectra obtained with the E1 apertures use the same reference files and parameters as those obtained with the nominal apertures. The purpose of the study reported here was to determine whether this was introducing significant wavelength calibration errors. The relative locations of lines within a spectrum are unlikely to change significantly by switching to the E1 aperture, but the zero point of the spectrum may shift. Thus, this study measured the mean wavelength difference between measured lines in the spectrum and reference lines from a catalog.

**Observations**

Wavelength calibration exposures using the HITM1 lamp were initially obtained in calibration program 9617. All exposures used the 52 × 0.1 E1 aperture. All first-order CCD spectral elements were used: G230LB, G230MB, G430L, G430M, G750L, and G750M, with all primary central wavelengths, and a few often-used secondary ones as well. However, it was found that there were insufficient counts in the 368 second exposure in the G230MB, \( \lambda_c = 1713 \) mode for program 9617. Therefore, this observation was repeated in calibration program 10025, with an exposure time of 1800 seconds.

Prior to the use of the E1 aperture, wavelength calibration was routinely done with the LINE lamp. However, the flux with this lamp at row 900 is much lower than at row 512. For example, for G430M, the ratio of the fluxes in these rows, \( f_{512}/f_{900} \), varies from 21 to 46, depending on the central wavelength setting. The HITM1 lamp results in much more favorable illumination, with \( f_{512}/f_{900} \approx 2 - 4 \) for all gratings and central wavelengths. Thus, the HITM1 lamp was used for the exposures analyzed here.

**Data Analysis**

For each grating a central wavelength, CALSTIS pipeline modules (Hodge et al. 1998; Brown et al. 2004) were run in the following order:

- *calstis1* (STSDAS task basic2d), to perform overscan, bias subtraction, dark subtraction, and flatfielding.
- *calstis2* (STSDAS task ocrreject), to detect and remove cosmic rays. This was done only for G230MB \( \lambda_c = 1854 \) and G230MB \( \lambda_c = 1713 \), for which CR-SPLIT=2 and CR-SPLIT=4, respectively. In all other cases, only a single exposure was made, so no cosmic ray removal was possible.
- *calstis7* and *calstis4* (STSDAS tasks x2d and wavecal). These are run only to compute SHIFTA1 and SHIFTA2, which account for offsets in the mode select mechanism (MSM). The data are not modified in these steps. These two keywords are written into the FITS header in the next step.
- *calstis12*, which updates the header information.
- *calstis6* (STSDAS task x1d) to produce a series of 1-D spectra.

Figure 1 shows an example a 2-D image of G430M \( \lambda_c = 4961 \). Many lines are present in this mode, allowing for a good estimate of the wavelength calibration errors. This image demonstrates how the flux from even the HITM1 lamp decreases near row 900, the approximate location of the E1 aperture.

The main goal of this study was to determine the accuracy of the wavelength calibration at the E1 aperture. However, it was simple to extend this by examining the calibration along the entire length of the CCD.
Thus, calstis6 was run on 32 separate sections of the chip, each consisting of 32 rows, grouped as follows: rows 1 – 32, 33 – 64, 65 – 96, ...992 – 1024. In each 32–row section, the data were summed in the cross-dispersion direction, resulting in a 1-D spectrum. Toward the edge of the detector, where the flux from the lamp is declining, the sum is dominated by the brightest rows, which introduces a slight wavelength error due to the tilt of the spectral lines.

The emission lines present in the 1-D spectrum near the center of the chip were compared to the cataloged lists of lines produced by Pt-Ne (http://physics.nist.gov/PhysRefData/platinum/contents.html) and and Pt-Ne-Cr (Don Lindler, private communication) lamps. The center of the chip is used for this initial line identification because this is where the illumination is best. Several 1-D spectra were compared to the line lists to be certain that a cosmic ray in the wavecal exposure was not masquerading as an emission line. In some cases there were only a few lines in the bandpass of a mode, and the ability to judge the wavelength calibration is compromised. In other cases there are many lines in the spectrum, and the comparison is straightforward.

Results

As mentioned above, for each grating and central wavelength, 32 1-D spectra were created. For each of these spectra, the centroid pixel locations of the emission lines were computed using the counts in each pixel as a weighting factor. This was found to give better results than fitting a gaussian to the emission lines, since the line was not well-sampled, with typically only about 3 pixels having counts significantly above the background. The measured centroid wavelengths were then compared to the catalog wavelengths, and the differences were tabulated. Figure 2 shows one example of a plot of these residuals, measured in pixels, as a function of wavelength. Each box corresponds to one 1-D spectrum. The number in the corner indicates the central row of the 32-row section summed to create the spectrum (i.e., 16.5 is the center of rows 1 – 32). Since the emission lines were undersampled, it was difficult to determine an accurate error. Therefore, the error on each residual plotted is taken to be \( \pm \left( \frac{\text{counts}}{2} \right)^{1/2} \), where \( \text{counts} \) is the number of counts in the spectral line. In some cases the error bar is too small to see on the plotted point. The horizontal line is the weighted average of all residuals in that box.

Table 16.1 in the STIS Instrument Handbook (Kim Quijano et al. 2003) specifies that the nominal relative wavelength calibration accuracy of the CCD spectroscopic modes is 0.1 – 0.3 pixels. To help guide the eye, the red vertical line near the right edge of each box in Figure 2 has a total length of 0.3 pixels.

The final results of this study are summarized in Figures 3 – 8, for the G230LB, G230MB, G430L, G430M, G750L, and G750M modes, respectively. For each grating and central wavelength, the weighted mean wavelength error in pixels is plotted as a function of CCD row in the top panel. The error bars on each point are equal to the RMS of the wavelength deviations between the measured and the cataloged spectral lines. The solid horizontal green line is the weighted mean of all points, but excluding the 3 highest and 3 lowest outliers, because these are often highly deviant due to cosmic rays, low flux, or lack of spectral lines at the particular setup. The green dashed lines are at \( \pm 0.15 \) pixels from the weighted mean, and indicate the width of the accuracy specified in the Instrument Handbook. A spline curve is fit through the data points to help indicate the behavior between plotted points. The G750M \( \lambda_c = 9851 \) setup is not shown because an insufficient number of cataloged spectral lines precluded an accurate assessment.

The bottom panel in Figures 3 – 8 shows the maximum deviation from the mean of any line in the spectrum used in this analysis. Large maximum deviations usually indicate difficulty in associating measured lines with cataloged lines, most likely due to poor lamp illumination at the E1 aperture.

It is immediately apparent from the top panel in Figure 3 that the wavelength calibration is generally very
good in the central portion of the CCD, where most STIS spectra of point sources have been obtained. In the region of rows 893 – 898, where the E1 aperture is located, most setups are within the 0.3 pixel specified error. The results are shown numerically in Table 1. For six setups the mean error is larger, but in these cases the uncertainties are large. In fact, it is clear from the increased size of the error bars for row numbers below ~ 100 and above ~ 925 that the flux from the HITM1 lamp is dropping rapidly, making the wavelength calibration less certain in these regions. The only case for which the allowable limit at the E1 aperture is formally exceeded is G750L $\lambda_c = 7751$, for which the mean wavelength calibration error is estimated to be $\sim 0.37$ pixels.

In conclusion, within the measurement errors the wavelength solution applied to observations of objects placed near the center of the CCD can be applied at the E1 apertures, except for the case of the G750L $\lambda_c = 7751$ setup. However, the ability to measure the calibration accuracy quickly degrades at row numbers greater than 900, so the wavelength calibration of extended objects placed at the E1 aperture may be slightly compromised.

**Acknowledgments**

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**References**

Hodge, P., Baum, S., McGrath, M., & Shaw, D., 1998, STIS ISR 1998-10, "Calstis0: Pipeline Calibration of STIS Data - A Detailed View".
Figure 1: The 2-dimensional, geometrically rectified image of the HITM1 wavecal exposure for G430M $\lambda_c = 4961$. Many spectral lines are present, allowing for a good estimate of the wavelength calibration errors in this case. Note how the intensity of the lines drops off at low and high row number. The E1 aperture is located at rows 893 – 898. The two horizontal black stripes are caused by the fiducial bars (Kim Quijano, et al. 2003).
Figure 2: The residual wavelength errors as a function of wavelength for the G430M \( \lambda_c = 4961 \) setup. Each box corresponds to a 1-D spectrum, whose location on the CCD is indicated by the number in the corner of the box. The error bars on each point are equal to \( \pm (\text{counts})^{-1/2} \). The horizontal red line is the weighted average of all the residuals in that box. The vertical red line near the right edge of each box is 0.3 pixels in length, the required accuracy of the wavelength calibration. Note how the errors are largest at very low and very high row numbers.
Figure 3: Top panel: the weighted mean wavelength error as a function of CCD row. The solid horizontal green line is the weighted mean of all the points, except for the 3 highest and lowest outliers, which are excluded. The dashed green lines are at ±0.15 pixels from the weighted mean, and indicate the width of the accuracy specified in the Instrument Handbook. A spline curve is fit through the data points. The E1 aperture is located at row ~ 895. Bottom panel: the maximum deviation of any measured line. Large deviations usually indicate difficulty in associating measured lines with cataloged lines, usually due to poor lamp illumination at the E1 aperture.
Figure 4: Same as Figure 3, but for the G230MB grating.
Figure 4 (continued)
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Figure 5: Same as Figure 3, but for the G430L grating.
Figure 6: Same as Figure 3, but for the G430M grating.
Figure 6 (continued)
Figure 6 (continued)
Figure 6 (continued)
Mean Wavelength Error (pixels)  g430m  \( \lambda_{\text{cen}}=3936 \)

Maximum Wavelength Deviation from Mean (pixels)

Figure 6 (continued)
Figure 6 (continued)
Figure 6 (continued)
Figure 6 (continued)
Figure 6 (continued)
Figure 6 (continued)
Figure 6 (continued)
Figure 6 (continued)
Figure 7: Same as Figure 3, but for the G750L grating.
Figure 8: Same as Figure 3, but for the G750M grating.
Figure 8 (continued)
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Figure 8 (continued)
Figure 8 (continued)
Figure 8 (continued)
Table 1: Summary of results of this study. The third column shows the difference between the mean wavelength error in rows 512 and 895, measured in pixels. If this number is greater than 0.3 pixels, it exceeds the relative wavelength accuracy specified in the STIS Instrument Handbook. However, in all cases except G750L $\lambda_c = 7751$, the difference is within the specification, given the measurement errors.
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**Table 1:** continued.