Post - SM4 Flux Calibration of the STIS Echelle Modes

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Abstract. Like all STIS spectroscopic modes, STIS echelle modes show a wavelength dependent decline in detector sensitivity with time. The echelle sensitivity is further affected by a time-dependent shift in the blaze function. To better correct the effects of the echelle sensitivity loss and the blaze function changes, we derive new baselines for echelle sensitivities from post-HST Servicing Mission 4 observations of the standard star G191-B2B. We present how these baseline sensitivities compare to pre-failure trends.

1. Introduction

The Space Telescope Imaging Spectrograph includes 2 medium and 2 high resolution ultraviolet (UV) echelle gratings, E140M, E230M, E140H, and E230H, with resolving powers of $R \sim 45,800$, 30,000, 114,000, and 114,000, respectively. These gratings provide the highest resolution spectra available on the Hubble Space Telescope (HST). There are multiple central wavelength settings or modes, available for each grating. A few central wavelengths in each grating are referred to as prime modes and the rest are denoted secondary modes. See the Chapter 13 in the STIS Instrument Handbook for a complete list of prime and secondary central wavelengths.

The absolute flux calibration of the echelle modes has proved particularly difficult. The initial calibration of the 12 prime modes was performed in 1998 (Bohlin, 1998). In 2006, prior to the reprocessing of STIS data, all echelle modes were recalibrated (Aloisi et al., 2007). Between 1998 and 2006, the characterization of many STIS features improved significantly. The 2006 sensitivity calibration includes these improvements as well as a correction for shifts in the blaze function (BF). It is also the first direct calibration of the secondary echelle modes and the first flux calibration of all echelle modes since the switch to Side 2 electronics in May 2001.

The STIS detector sensitivity has been shown to decline smoothly with wavelength over time. Additionally, large temperature changes (such as the switch from Side 1 to Side 2 electronics) can cause elements within the instrument to shift, creating unpredictable shifts in the echelle BF. For this reason, when STIS was restarted in May 2009, after HST Servicing Mission 4 (SM4), a program was undertaken to characterize the sensitivity of the echelle modes for post - SM4 data.

2. Observations

All observations were taken as part of the Cycle 17 calibration program 11866. The HST primary standard star G191-B2B, a DA white dwarf, was observed in all modes using the $0.2'' \times 0.2''$ aperture. Unlike previous calibrations, all data was taken in the zero monthly offset position (monthly offsetting was disabled for echelle modes in August 2002), creating a more uniform data set. All observations were taken between November 25, 2009 and January 6, 2010. Exposure times were set to obtain a peak signal-to-noise (S/N) ratio of
30 in each central wavelength for the E140M, E140H, and E230M grating and a S/N ratio of 20 for the E230H grating. For the three most commonly used Cycle 17 FUV modes (E140H/1234, E140M/1425, E140H/1343), exposure times were chosen to obtain a S/N ratio of 100.

3. Analysis

This analysis closely follows that of Bohlin (1998) and Aloisi et al (2007). First the sensitivity curves for each order are found. The sensitivity curves are then combined with the blaze function to create the photometric throughput (PHT) tables, which are used by CALSTIS in the absolute flux calibration of STIS data.

3.1. Finding the Sensitivity Curves for Each Order

The sensitivity curve of each order in a central wavelength is determined by performing three spline fits: one across each order (in the dispersion direction), one to the average sensitivity of each spectral order, and one across the spectral orders for each node defined in the first fit.

The observed count rate is divided by the model flux spectrum, which has been interpolated to the observed wavelength scale. This is done for each order, m, of an extracted spectrum (x1d file), creating a sensitivity curve for each order. A 7 (9 for E230M) node spline fit is made to the median smoothed sensitivity spectrum, placing the nodes, \(N(i,m)\), (where \(i\) is the node number within an order) at constant x pixel locations (where the x axis is defined horizontally in the same direction as the increasing wavelengths within a given order). The median smoothing smoothes many narrow absorption lines which are in the observed spectrum, but not in the model spectrum. In some cases, this smoothing is insufficient and the line must be masked or the entire order excluded from the final fit. Additionally, pixels with bad data quality flags are excluded from the fit.

The sensitivity values of these nodes are averaged to create an average sensitivity for each order. A spline fit is then performed to the average values and the fit used as the average sensitivity for each order, \(A(m)\).

Next, the nodes are normalized by the average sensitivity of a given order, \(N_{\text{norm}}(i,m) = N(i,m)/A(m)\). All normalized nodes at a single x pixel location are fit, smoothing vertically along the detector. The normalization brings all node values at a given x pixel location to approximately the same sensitivity, making them easier to fit. A spline fit is used again, with closely spaced nodes for the end orders and a few widely spaced nodes for the middle orders. This fit primarily smooths out any lingering abnormal features (such as absorption lines or bad data). The values of this spline fit at the original nodes, \(N(i,m)\), for each order are multiplied by the average to obtain the original sensitivity and are then written to a file with the corresponding wavelengths.

Finally, if more than one observation exists for a given grating and central wavelength, then the two files are combined and weighted by exposure time.

3.2. Blaze Function

A blaze function (BF) is an optical throughput curve that describes the change in sensitivity of a grating across a detector. Two of the variables that affect the BF are the incident light angle on the grating and the angle of the grating with respect to the detector. In general, the BF is optimized so that its peak falls on the center of the detector. However, the change in position of a spectrum on a detector is indicative of a change in grating position or incident light angle, and therefore means a shift in the BF. In a static system, the BF shift is simply a function of detector location: observed wavelength (OBSW) and cross-dispersion location (OBSY). However, STIS is more complicated. The mode select mechanism (MSM) is a
nutating wheel, allowing a grating to move in all three dimensions. Hence, the BF does not shift by the same amount as the spectrum. Additionally, there appears to be a drift of the BF with time (and thus a time dependence) as well as an offset which is thought to be the result of the flexing of the instrument with large thermal changes. The BF shift equation, as defined in Aloisi et al. (2007), is:

$$B_{SHIFT} = B_{SHIFT_{VS, X}} \Delta x + B_{SHIFT_{VS, Y}} \Delta y + B_{SHIFT_{VS, T}} \Delta t + B_{SHIFT_{OFFSET}}$$  \hspace{1cm} (1)$$

where

$$\Delta x = (REFWAV - OBSW)/DISP$$

$$\Delta y = OBSY - REFY$$

$$\Delta t = OBSDATE - REF\text{MJD}.$$

REFWAV and REFY are the wavelength and cross-dispersion position, respectively, of the reference spectral order at pixel x = 512. OBSDATE is the observation date in Modified Julian Days (MJD) and REFJMJD is the MJD of the observation used to infer the sensitivity of the echelle mode. $B_{SHIFT_{VS, X}}$ and $B_{SHIFT_{VS, Y}}$ are functions of detector location and vary only with grating. $B_{SHIFT_{VS, T}}$ and $B_{SHIFT_{OFFSET}}$ vary with grating, order, and Side (Side1, Side2, or Side2 repaired electronics). The temporal components of the BF shift ($B_{SHIFT_{T}}$ and $B_{SHIFT_{OFFSET}}$) reflect changes with time since the sensitivity curves were created. As we created new sensitivity files, these were 0.

3.3. Creating the PHT Table

The sensitivity curves must be corrected to meet the PHT table sensitivity definitions. Specifically, the sensitivity curves are derived from count rates observed through a $0.2'' \times 0.2''$ aperture and extracted using a 7 pixel high extraction region. The net counts are corrected to an infinite extraction region and aperture. Additionally, the sensitivity of the detector has decreased over time at a rate that is wavelength dependent. The sensitivity curves are measurements of the degraded sensitivity as of Cycle 17. The PHT table assumes sensitivity measurements from the beginning of STIS operations in 1997. The time-dependent changes in the sensitivity are therefore removed from the sensitivity curves. The sensitivity is also converted to throughput. The correct throughput values and the BF shift coefficients are then written to the PHT table. One table is made for each detector.

4. Results

A PHT table is tested by running the STScI calibration pipeline program, CalSTIS, on data from the SMOV program 11403 and the Cycle 17 program 11860. These programs periodically observe the HST secondary standard star BD+28°D4211 to monitor changes in sensitivity of the STIS detectors. The programs were chosen as they observe a source with a reference spectrum and have observations which are taken at regular intervals. CALSTIS is run twice on observations from August and September 2009 and April and June 2010, once with the current PHT table (currently used by OPUS for On the Fly Reprocessing) and once with the new PHT table. The flux from both these calibrations is plotted together with the reference spectrum. While the overall sensitivity level is expected to be the same (since it is corrected with the time-dependent sensitivity files) the shape and location of the blaze function is expected to have changed, causing the data calibrated with the current PHT table to show arcs in each order. The data calibrated with the new PHT table should follow the reference spectrum closely. This result can be seen in Figure 1, where the green line is the data calibrated with the new PHT table, the red line is the data calibrated with
the current PHT table, and the black line is the reference spectrum. The inset plot shows that the new PHT table spectrum matches the reference spectrum much better than the current PHT table spectrum.

Figure 1: A plot of the flux calibration of the HST standard star BD +28D4211A. This data was taken as part of the sensitivity monitoring program in June 2010 using the E140M grating. In the plot, a clear comparison can be drawn between the reference spectrum (black line) and a spectrum calibrated with the new PHT table (green line) and the current PHT table (red line). Inset is the same plot for the wavelength range 1550-1610. In this plot, the BF is clearly being calibrated incorrectly with the current PHT table as the BF arc of each order is apparent in the red line but not in the green line.

4.1. E140H Anomaly

Sensitivity monitoring data from the E140H grating showed a much lower sensitivity than anticipated in August 2009. Since the anomaly was first detected, the sensitivity has steady increased to close to expected levels. A comparison of April and June data show that the sensitivity is continuing to increase. As the echelle flux calibration data was taken between November 2009 and January 2010, it is possible that it has been impacted by the anomaly. The anomaly would affect the flux calibration by artificially increasing the flux above the reference spectrum. Figure 2, shows the behavior of the anomaly over time. While the spectrum calibrated with the new PHT table is systematically higher than the spectrum
calibrated with the current PHT table, there is no evidence that the new PHT table is over correcting the flux above the reference spectrum. Additional monitoring data obtained in September 2010 will be used to confirm the validity of the new PHT table prior its implementation as a reference file.

Figure 2: Sensitivity monitoring over time of the HST standard star BD+28D4211. The black line is the reference spectrum, the green line is the data calibrated with the new PHT table, and the red line is data calibrated with the current PHT table. The date each observation was taken is given at the top of each plot. From these plot, the E140H anomaly is clearly visible, as is its evolution over time towards the expected sensitivity.

5. Conclusion

The absolute flux calibration of the STIS echelle modes post-HST SM4 was undertaken to accurately correct the blaze function and the decreased sensitivity of the detectors over time. Observations of the white dwarf G191-B2B were taken and used to create sensitivity curves. These curves were corrected and combined with the blaze function files to create new PHT tables. The new PHT tables were used to calibrate observations of the star BD+28D4211 and results were compared to results from the current PHT tables. It was found that the new PHT tables provide a better absolute flux calibration than the current PHT tables.
through a better characterization of the blaze function shift and sensitivity curves. These files will be implemented in On the Fly Reprocessing of post HST-SM4 data.

References


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