Trace and Wavelength Calibrations of the HST/ACS G800L Grism

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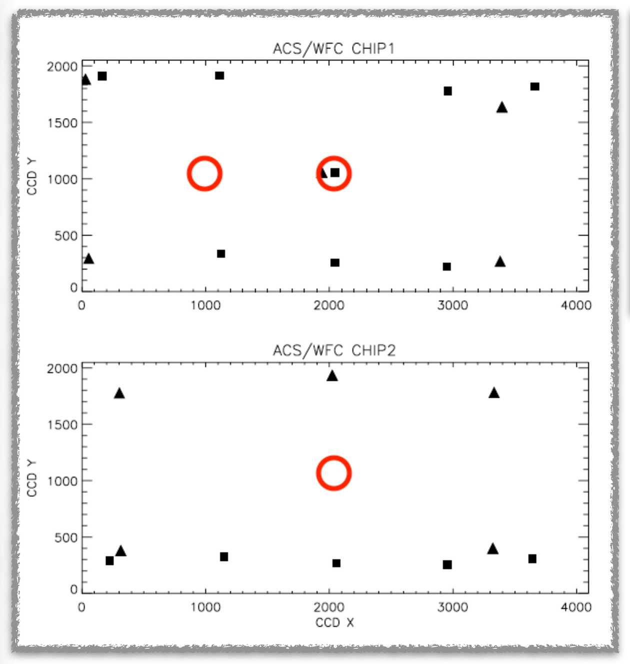
Introduction

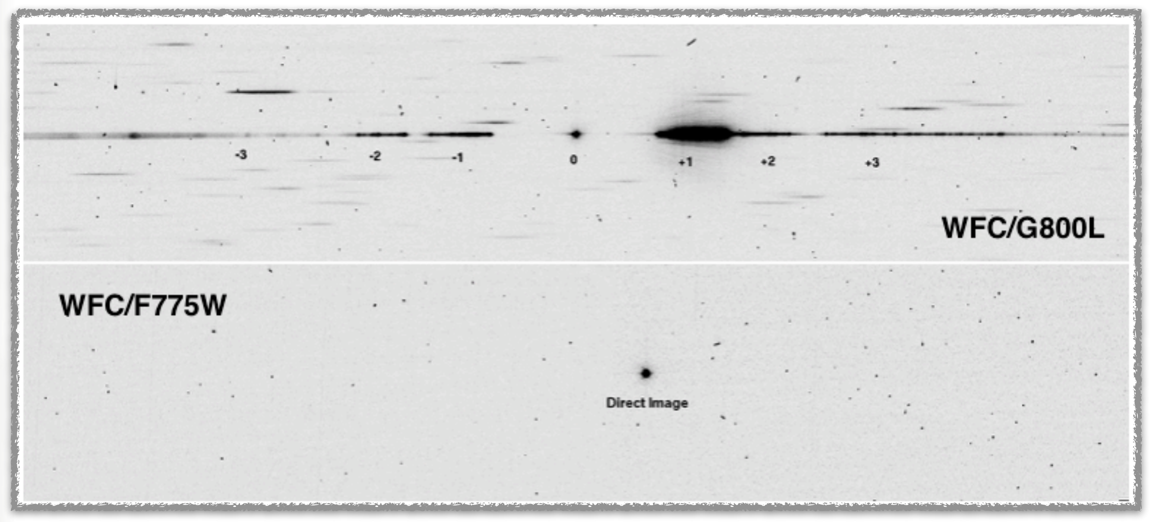
The HST/ACS G800L grism, an optical slit-less spectroscopy mode on ACS, has been very stable since its inception in 2002, but no major effort to improve its trace and wavelength calibrations has been attempted since 2005 (Larsen+ 2005). The accurate calibration of the spectral trace and the dispersion solution are crucial to locate the spectrum in the grism image as well as to precisely identify spectral features in a spectrum.

We obtained new observations of an emission line Wolf-Rayet star (WR96) in the HST Cycle 25 (PID: 15401) to undertake a thorough analysis of verifying (Hathi+ 2019) and improving the ACS grism calibrations. To account for the field dependence, we observed WR96 at 3 different observing positions over the ACS field of view (FoV), but that is inadequate coverage to properly sample the entire ACS field of view.



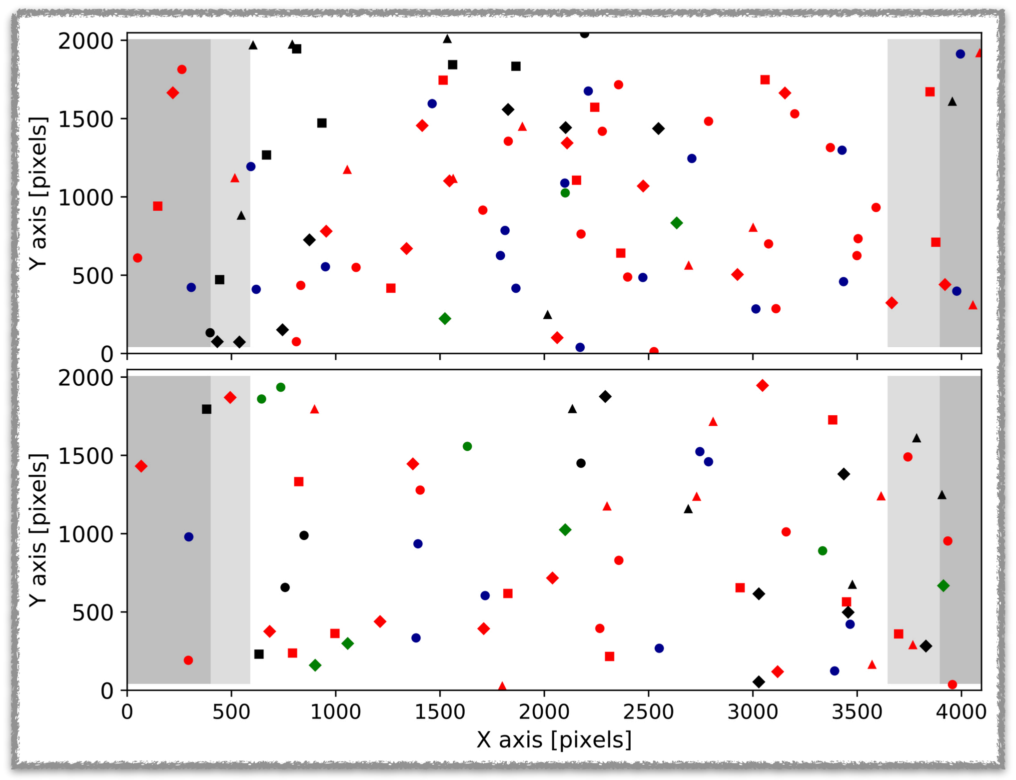
◄ Observing positions of WR96 — red circles (2018) and black symbols (2002–2003; Pasquali+ 2003, 2006)

Direct image (F775W) and grism image (G800L) of WR96 ▼

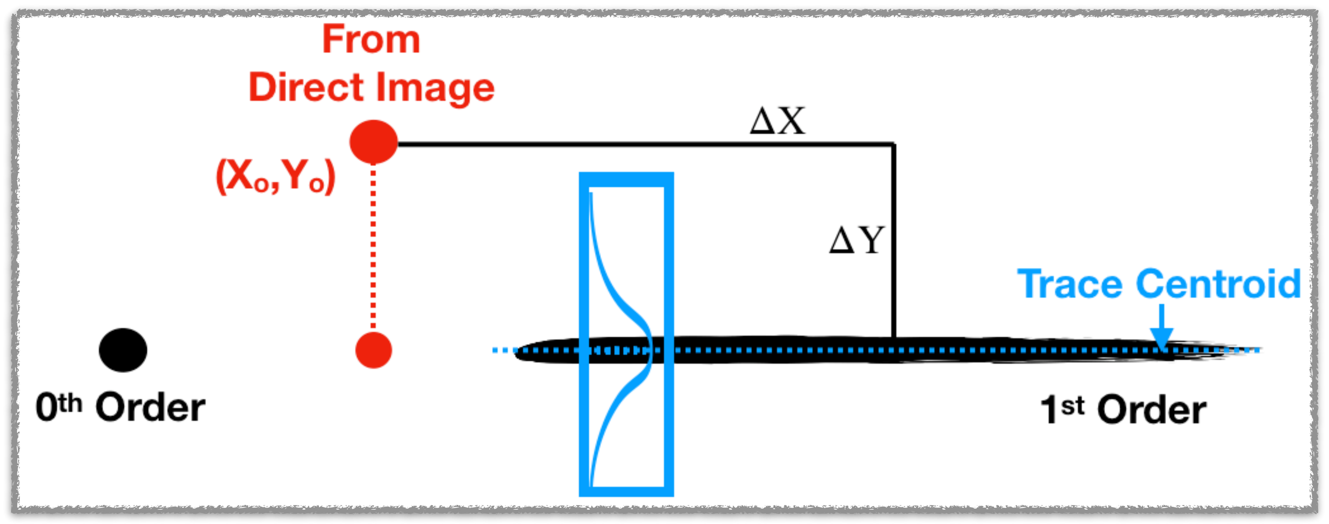


To account for proper sampling, we are reprocessing all the archival ACS grism data that has bright stars in the FoV. By combining all data we can now derive a more finely sampled field dependence of the grism dispersion solutions. These data, combined with the new approach (Pirzkal+ 2016) to solving for the polynomial coefficients of the field dependence of both the trace and wavelength calibrations, allow us to improve the accuracy of the grism calibration.

Trace Measurements and Fitting



Archival images with bright field stars are selected to properly sample both CCDs. The objects in the shaded regions on the right are not useful for +1st and +2nd orders, while objects in the shaded regions on the left are not useful for -1st and -2nd orders because they fall outside the ACS FoV. Different colors (shapes) denote different programs (images). With many stars over the ACS FoV and with each star having 150 trace points, we can solve Equation 3 to obtain 12 {b} coefficients.



Calibrating the trace of the grism involves determining the location of the spectra on the detector when the source is known to be at a given pixel. It essentially consists of carefully tracing the spectrum of the source and keeping track of the centroid (in the y direction) of the spectrum and keeping track of the measured y-offset between the spectrum and the source for increasing values of x.

The program aXe requires a polynomial description of both the spectral trace and of the wavelength solution for each order of the grism. The trace, for each order, is parameterized by Equation 1 (Pirzkal+ 2016). Where $\triangle y$ is the offset (in pixels) between the centroid of the trace and the y position (Y_0) of the source, $\triangle x$ is the offset in the x-direction between a particular pixel on the trace and the x-position (X_0) of the reference pixel (as shown above). The order of the polynomial is n and a linear dispersion would simply be obtained with n = 1.

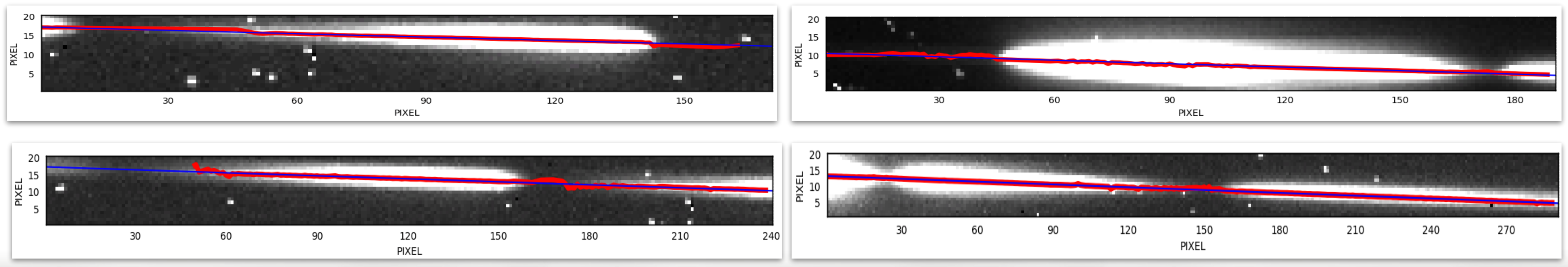
$$\Delta y(\Delta x) = a_1 \times \Delta x + a_2 \times \Delta x^2 + \ldots + a_n \times \Delta x^n \qquad (1)$$

If ACS had no field dependence, then coefficients {a} would be constants but because of geometric distortion there is a significant amount of field dependence. This field dependence is parameterized by allowing {a} to itself be a 2D polynomial and a function of the position of the reference pixel (X_0,Y_0) as shown in Equation 2.

$$a_i(x_0, y_0) = b_{i,1} + b_{i,2} \times x_0 + b_{i,3} \times y_0 + b_{i,4} \times x_0^2 + b_{i,5} \times x_0 \times y_0 + b_{i,6} \times y_0^2 \qquad (2)$$

For simple linear dispersion (n=1), substituting Equation 1 into Equation 2 gives Equation 3

$$\Delta y(x_0, y_0, \Delta x) = b_{0,0} + b_{0,1} \times x_0 + b_{0,2} \times y_0 + b_{0,3} \times x_0^2 + b_{0,4} \times x_0 \times y_0 + b_{0,5} \times y_0^2 + \Delta x \times (b_{1,0} + b_{1,1} \times x_0 + b_{1,2} \times y_0 + b_{1,3} \times x_0^2 + b_{1,4} \times x_0 \times y_0 + b_{1,5} \times y_0^2) \qquad (3)$$



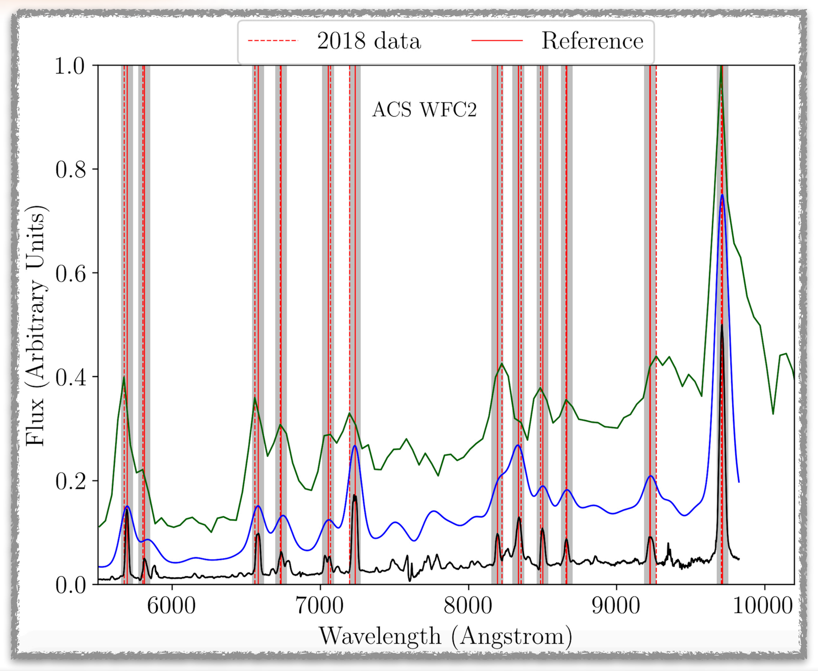
Example trace measurements are shown on the left. Top-left is -1st order, top-right is +1st order, bottom-left is -2nd order and bottom-right is +2nd order. Spectral tilt measurements (about -2 deg) are consistent with Pasquali+ 2003, 2006

Ongoing work — Wavelength Calibration

A spectrum is wavelength calibrated by relating the displacement Δp of a pixel along the trace, to the wavelength of that pixel using a function Δλ = λ(Δp). aXe requires this Δp to be path length, along the trace, between the pixel of interest and a reference position on the trace (X_0, x-coordinate of the direct image). Similar to Equation 3, we can parameterized λ(Δp) as:

$$\lambda(x_0, y_0, \Delta p) = \lambda_{0,0} + \lambda_{0,1} \times x_0 + \lambda_{0,2} \times y_0 + \lambda_{0,3} \times x_0^2 + \lambda_{0,4} \times x_0 \times y_0 + \lambda_{0,5} \times y_0^2 + \Delta p \times (\lambda_{1,0} + \lambda_{1,1} \times x_0 + \lambda_{1,2} \times y_0 + \lambda_{1,3} \times x_0^2 + \lambda_{1,4} \times x_0 \times y_0 + \lambda_{0,5} \times y_0^2)$$

Where (X_0,Y_0) are x and y coordinates of the source in the direct image, Δp is the path length along the trace and {λ} are the parameters describing the dispersion relation and its field dependence. New trace calibrations are implemented in aXe and the wavelength dispersion set to unity so extracted 1D spectra are not wavelength calibrated but are function of Δp. We can measure positions of bright emission lines in these 1D spectra. By knowing the line centers (through gaussian profile fits), reference wavelengths, and x/y coordinates of the direct image we can solve for {λ} in the above equation. After implementing the new wavelength calibration in aXe, it is possible to test this new dispersion solution against the existing (2005) solution.



Current wavelength calibration as measured by Larsen+ 2005 and it shows differences between the measured and reference wavelengths that are as high as 40Å (gray shades). We hope to improve the calibration through this new, WFC3 tested, approach.

References

- Pasquali+ 2003, ST-ECF ISR ACS 2003-001;
- Pasquali+ 2006, PASP, 118, 270;
- Larsen+ 2005, ST-ECF ISR ACS 2005-08;
- Pirzkal+ 2016, STScI ISR WFC3 2016-15;
- Hathi+ 2019, STScI ISR ACS 2019-01