Advances on Hubble Wide Field Camera 3 Grism Calibration and Slitless Spectroscopy Analysis

Fowler, J., Brammer, G., Ryan, R., Deustua, S., & Pirzkal, N.

Space Telescope Science Institute

Abstract

Grisms are spectral elements combining a grating and prism to conduct slitless spectrsocopy; presently they make up approximately 13% of all Wide Field Camera 3 (WFC3) observations on the Hubble Space Telescope (HST). WFC3 contains three grisms, two for the infrared (IR) channel and one for the ultraviolet-visible (UVIS). Here we summarize recent results from an ongoing effort to improve the analysis tools, characterization, and calibration of WFC3 slitless spectroscopic observations. This includes (1) IR linear-reconstruction solving methods that solve for optimal, non-parametric spectra,(2) calibrating the IR wavelength solutions with respect to compact zeroth order images, (3) improved IR throughput curves from modeling grism flux by extending the pixel range of effective point spread functions, (4) calibrating the UVIS +1 and -1 order over the entire field of view of both chips (allowing for spectral extraction from the entire UVIS detector.) With these efforts we continue to improve and advance the science possible with WFC3 grism observations.

(1) IR Linear Reconstruction Solving Methods

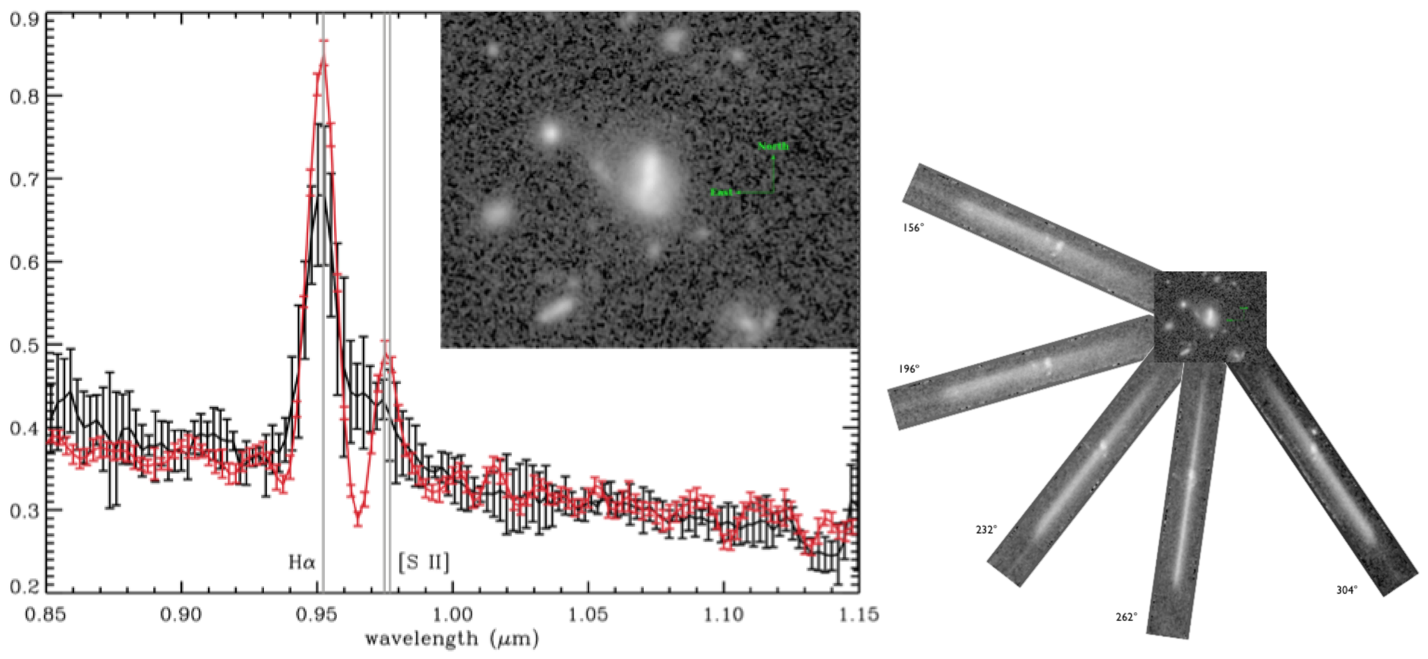

Figure 1: *A J∼ 22 mag galaxy in GOODS-N observed in five orients. Spectrum from the* `LINEAR` *algorithm is shown in red and standard orient-averaged shown in black.* `LINEAR` *improves the spectral resolution without sacrificing S/N, a trade-off made by standard techniques. The "algorithm paper" has been accepted to PASP and the code will be available on* `GitHub`*. See poster* **Ryan, Casertano, Pirzkal 150.24** *and/or email rryan@stsci.edu for more details or preliminary code.*

(2) Improved IR Wavelength Solutions

The traditional method of assigning a wavelength scale for WFC3 grism spectra is based on offsets from an associated direct image, known as the Direct Image Method (DIM). However, wavelength assignments for sources with known coordinates can be derived using the offsets from the zero order grism images, or Zero Order spectral Extraction (ZOE). The rms precision of the assigned wavelengths for individual spectra is better than 0.2 pixels.

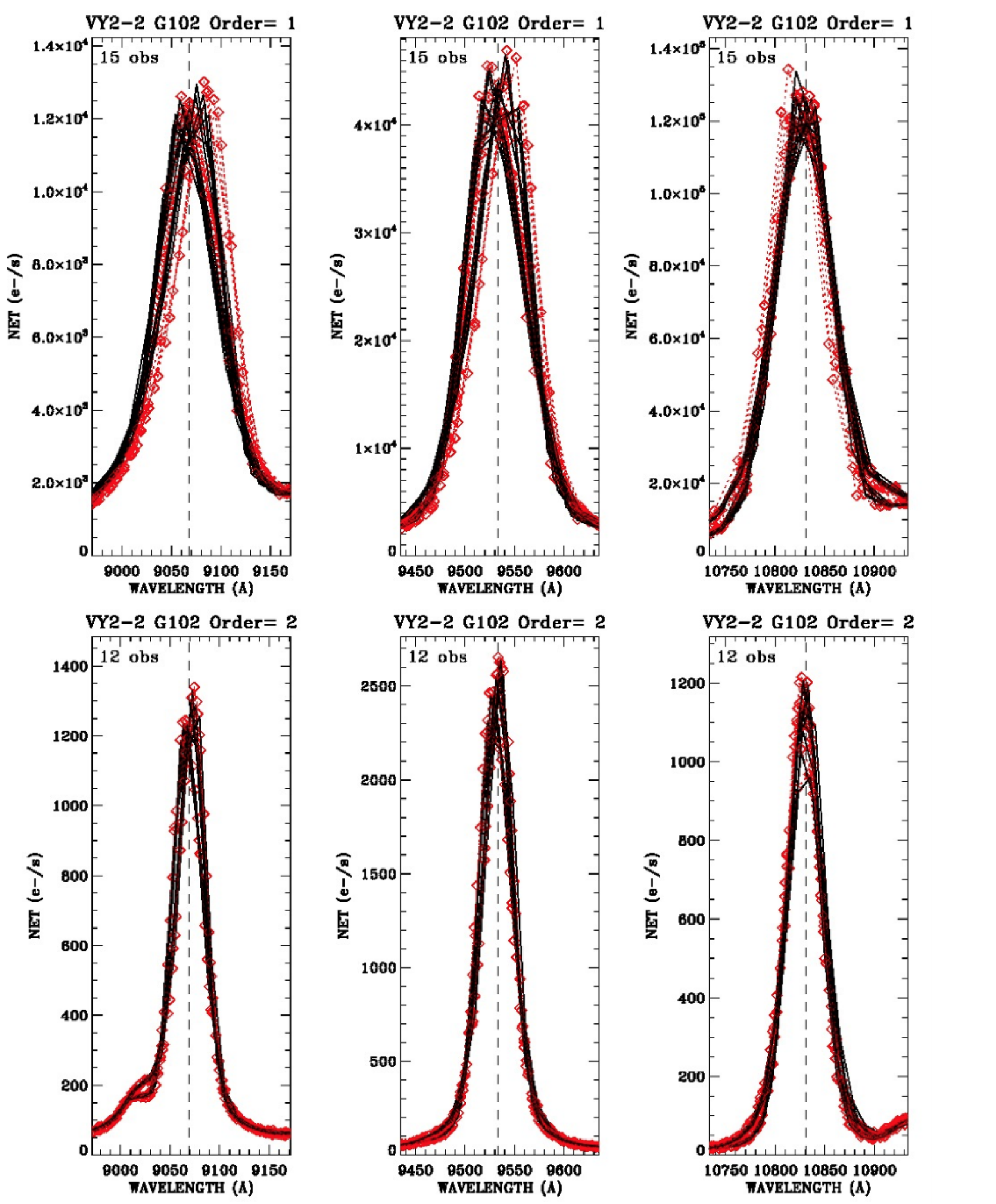

Figure 2: *The G102 WFC3 reference emission line profiles of Vy2-2 on a vacuum wavelength scale. All the spectra from programs 11937 and 13093 with both ZOE (black) and aXe (red) wavelength solutions are overplotted with the number of observations indicated. The vertical dashed lines are at the reference wavelengths for the −71 km/s radial velocity of Vy2-2.*

Grism	Order	9072 Å	9535 Å	10833 Å	12822 Å	16412 Å	N (images)
G102	-1	2.2	2.3	2.6	–	–	6
G102	+1	5.3	5.0	4.6	–	–	27
G102	+2	5.0	4.1	3.1	–	–	16
G141	-1	–	–	5.1	3.0	7.0	15
G141	+1	–	–	6.5	7.6	7.9	27
G141	+2	–	–	5.5	6.3	–	20

Table 1: *Rms standard deviation of the errors in Å for the three measured lines for each grism.*

(2) Cont'd

Grism	Order	Line (Å)	Mean (Å)	N (images)
G102	-1	9535	2.4	6
G102	+1	9535	-1.2	27
G102	+2	9535	-2.2	16
G141	-1	12822	5.2	15
G141	+1	12822	-1.3	27

Table 2: *Mean offset in Å of the two emission lines used as an independent verification.*

(3) Improved IR Throughput Curves

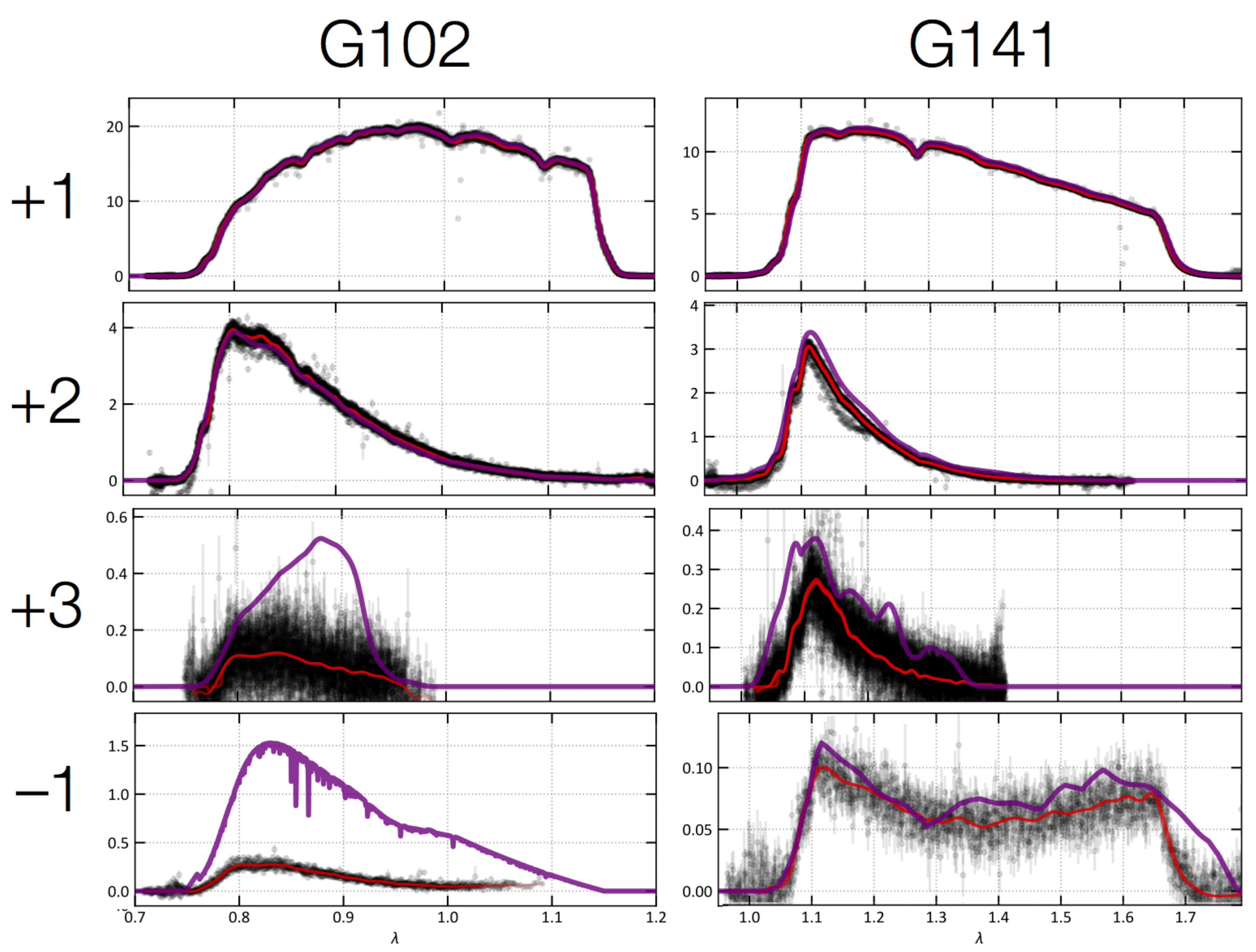

Figure 3: *Extracted WFC3/IR grism spectra for the WD calibrator star GD71. The brightest primary order(+1) is shown along with the additional higher-order spectra. The purple curves show the predicted spectra based on the CalSpec model for GD71 and the current grism throughput calibration curves, and the red curves show the best fit to the observed contamination modeling of WFC3 wide-field slitless spectroscopic observations.*

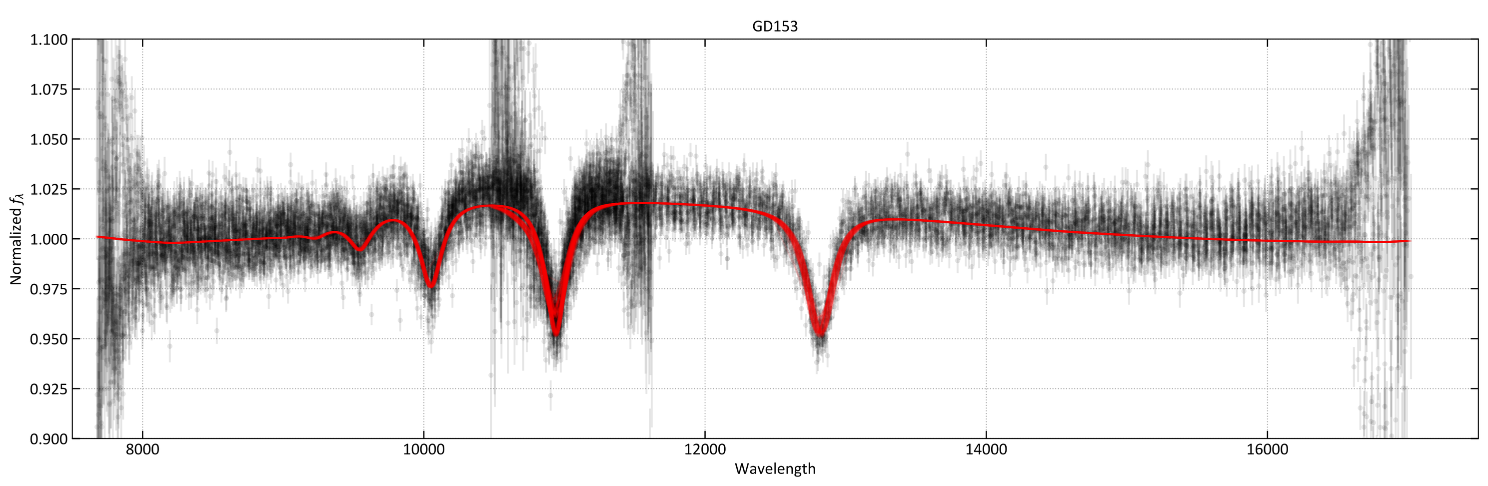

Figure 4: *WFC3/IR grism spectra of the WD calibrator star GD153. The steep blue continuum has been normalized out, with the prominent Paschen-series absorption lines remaining. The observed data taken from calibration programs spanning the 8 years since SM4 and with the target placed all around the detector field of view are shown in black; the CalSpec model spectrum is shown in red. Excluding the edges of the grism bandpass where the throughput falls of rapidly (Figure 3), the absolute flux calibration of both grisms is determined with a precision of < 2% across the bandpass, and the calibration is stable both temporally and spatially.*

(4) UVIS Grism Calibration

The new UVIS grism calibration is based on in-flight observations of the star WR14 which was observed at multiple positions on the UVIS detector. This allowed us to derive a first estimate of the field dependence of the UVIS G280 dispersion. While previous TV3 ground test based calibration was only able to calibrate spectra obtained at the center of the UVIS CHIP1, our new solutions allow for the extraction and wavelength calibration of spectra over the entire UVIS field-of-view and for both CHIP1 and CHIP2. We estimate the accuracy of the wavelength calibration using the new V2.0 dispersion solutions to be ±7Å, or about half of a UVIS resoution element.

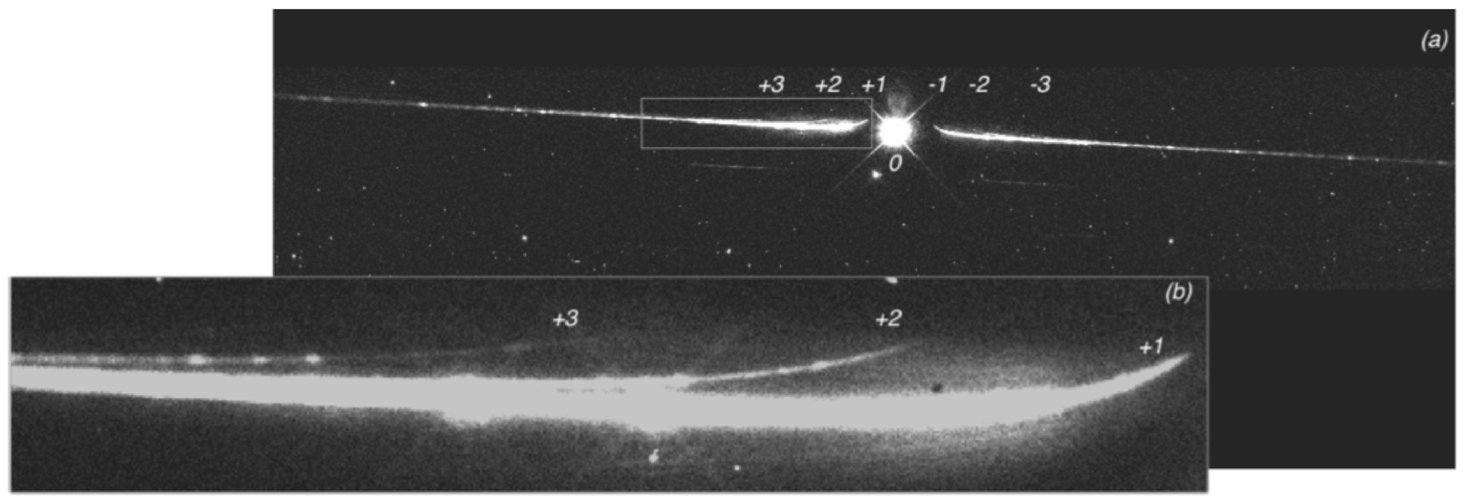

Figure 5: *UVIS G280 spectrum of WR14. The UVIS G280 grism offers a unique slitless mode spanning the wide wavelength range of approximately $2000 < \lambda < 8000$Å. Unlike the WFC3 G102 and G141 grism, however, the G280 spectra are strongly curved, multiple orders overlap at longer wavelengths, and the -1 is not well suppressed and is only about half as bright as the +1 order.*

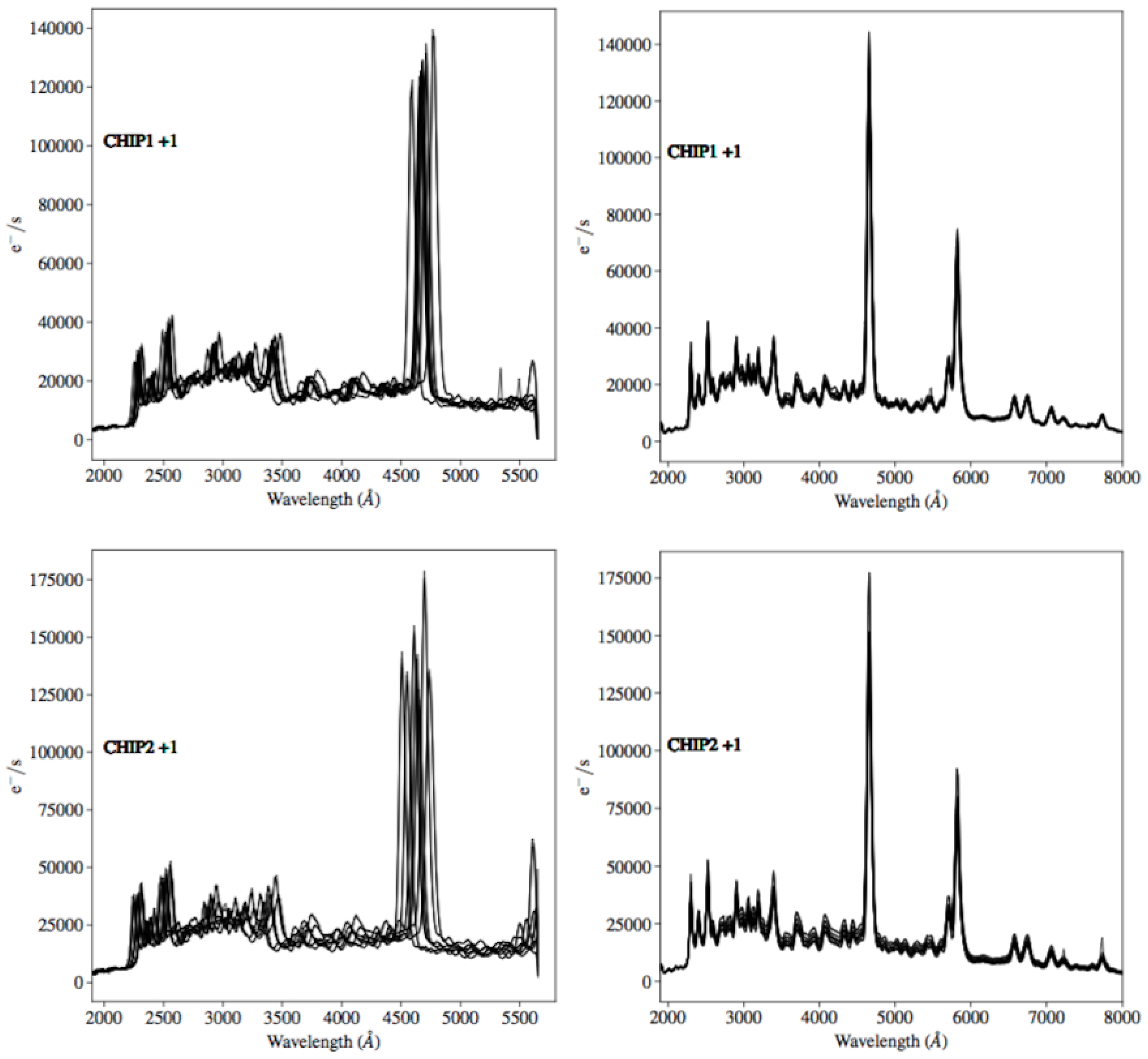

Figure 6: *A total of 22 +1 order spectra in CHIP1 and CHIP2. Left: Extraction using previous calibration. Right: Extraction using the V2.0 calibration of the G280 grism. A qualitative comparison shows a tighter agreement between all the extracted spectra as well as the increased wavelength span of the of the calibrated data. The disagreement in flux on the blue sides of is expected and caused by the highly curved nature of the spectra, resulting in self contamination that is not corrected for. (The -1 order spectra shows similar improvement, see Pirzal et al. 2017 for details.)*

Acknowledgements

Many thanks to Elena Sabbi and the WFC3 Team for sending me to AAS to present this poster! Also to Matthew Bourque who provided insightful poster feedback.

References

ISR 2015-10: IR Grism Wavelength Solutions Using the Zero Order Image as the Reference Point, Bohlin, R.C., Deustua, S. E., Pirzkal, N. 30 June 2015

ISR 2018: Throughput Updates to the WFC3/IR Grism Configuration Files, Brammer, G. Fowler, J., Jan 2018 (in prep)

ISR 2017-20: Trace And Wavelength Calibrations of the UVIS G280 +1/-2 Grism Orders, Pirzkal, N., Hilbert, B., Rotherberg, B. 21 June 2017

Ryan, R., Casertano, S, Pirzkal, N. (2018, PASP accepted), "Linear: A Novel Algorithm for Reconstructing Slitless Spectroscopy from HST/WFC3"