ABSTRACT

The dispersion relation for the *Chandra* Low Energy Transmission Grating Spectrometer (LETGS) is known to better than 1 part in 1000 over the wavelength range 5-150 Å. However, data acquired during in-flight calibration with the HRC-S shows the presence of systematic non-linear deviations in the positions of some spectral lines by as much as 0.05 Å. These effects are thought to be caused by spatial non-linearities in the imaging characteristics of the HRC-S detector. Here, we present an improved dispersion relation for the LETG+HRC-S and new methods to help characterize the spatial non-linearities. We also present an empirical approach that is shown to improve the observed non-linearities of the dispersion relation.

Observations

α Aur (Capella) is an active binary with an emission line spectrum comprised of many bright and narrow lines. This makes it an ideal target for our calibration analyses, which involve cross-correlating spectra and wavelength centroiding. We also used data from cataclysmic variables WZ Sagittae and AM Herculis. WZ Sge is useful for calibrating the outer plates since most of its features lie at the longer wavelengths (where there are few lines from Capella).

Table 1: Observations used in our analyses.

Target Name	ObsID	Exposure [ks]	Start Date	offset [arcmin]
α Aur	1248	85.23	1999 Nov 9 13:27:21	0
α Aur	62435	32.71	1999 Sep 6 00:26:17	0
α Aur	58	34.11	2000 Mar 8 06:29:47	0
α Aur	1009	26.97	2001 Feb 14 11:40:43	0
α Aur	2582	28.83	2002 Oct 4 23:57:53	-1.5
α Aur	3479	30.38	2002 Oct 6 10:01:58	1.5
WZ Sge	2504	20.00	2001 Jul 27 02:30:22	0
AM Her	645	24.11	2000 Sep 30 13:52:40	0

Analysis

Cross-Correlation

- Coadd events from different observations whose 0th order dither pattern lands within a given region of `tdety` (detector coordinate along the dispersion direction). Cross correlate spectra extracted from the different `tdety` regions to determine the wavelength non-linearities over specific detector scales.
- This analysis is capable of mapping out distortions across a wide range of the detector, given that we can coadd sources whose spectra show features at different wavelengths.

Line-Centroiding

- Examine events in λ versus `tdety` space (**Figure 5**), where `tdety` is the detector coordinate along the dispersion direction. Bin events into slices of `tdety` and histogram across wavelength, then fit a modified Lorentzian function to the histograms to obtain wavelength centroids. Compare measured wavelength centroids with reference wavelengths and map out distortions along `tdety` (**Figure 6**).
- Lines with good signal-to-noise are necessary for this method since it is dependent on accurate centroiding of events along `tdety`. Range of detector space over which we can map out distortions is limited by the number and location of lines in our spectra.

Summary & Future Work

- From cross-correlation analysis, we see non-linearities of magnitudes $\sim$ 0.04 Å on the central plate over scales ranging from 100 to 300 detector pixels. Distortions along the outer plates are larger, with magnitudes up to $\sim$ 0.1 Å (**Figure 3**).

- Line centroiding analysis yields results that are consistent with cross-correlation analysis. Again, we see distortions of order $\sim$ 0.05 Å for the central plate and larger distortions on the outer plates (**Figure 6**).

- By adopting a new empirically based HRC-S degap map, we see some improvement in the non-linearities of the dispersion relation by up to 0.03 Å. However, much of the non-linear distortions are still observed on the central and outer plates.

- Await further observations (data are taken from Guest Observer (GO) observations) whose spectra show features at longer wavelengths, and apply cross-correlation analysis to map out wavelength non-linearities along the outer plates of the HRC-S.

Acknowledgments

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References

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2. van der Meer et al, Nov. 2001 CXC Calibration Workshop
Non-linearities in the HRC-S Detector
http://cxc.harvard.edu/ccw/proceedings/presentations/van_der_Meer

3. Kashyap et al, Nov. 2001 CXC Calibration Workshop
Imaging characteristics affecting the LETGS
http://cxc.harvard.edu/ccw/proceedings/presentations/v_kashyap

4. Weisskopf et al, in Proc. SPIE Vol. 485, p.1-16, 2003

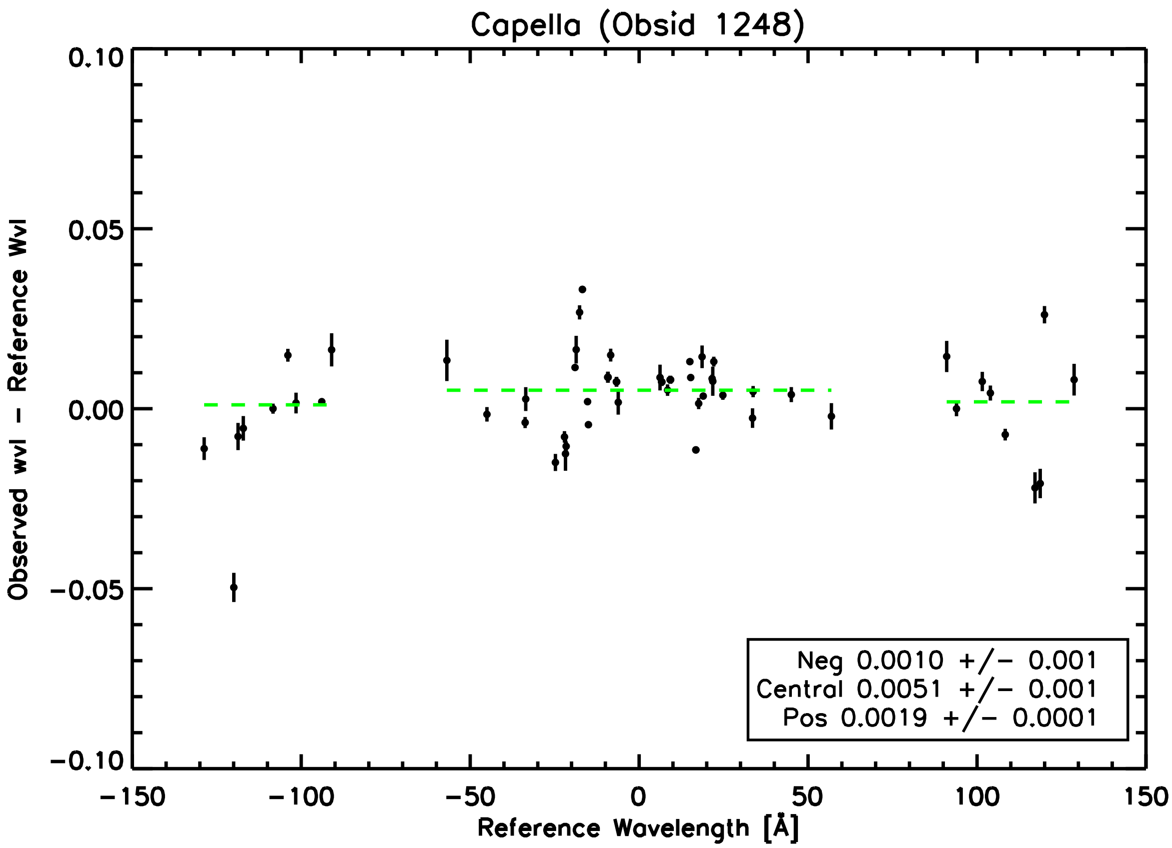


Fig. 1.— The dispersion relation for HRC-S+LETG. Non-linearities are visible on all three micro-channel plate segments. The root-mean-square (RMS) deviation across all wavelengths is 0.013 Å.

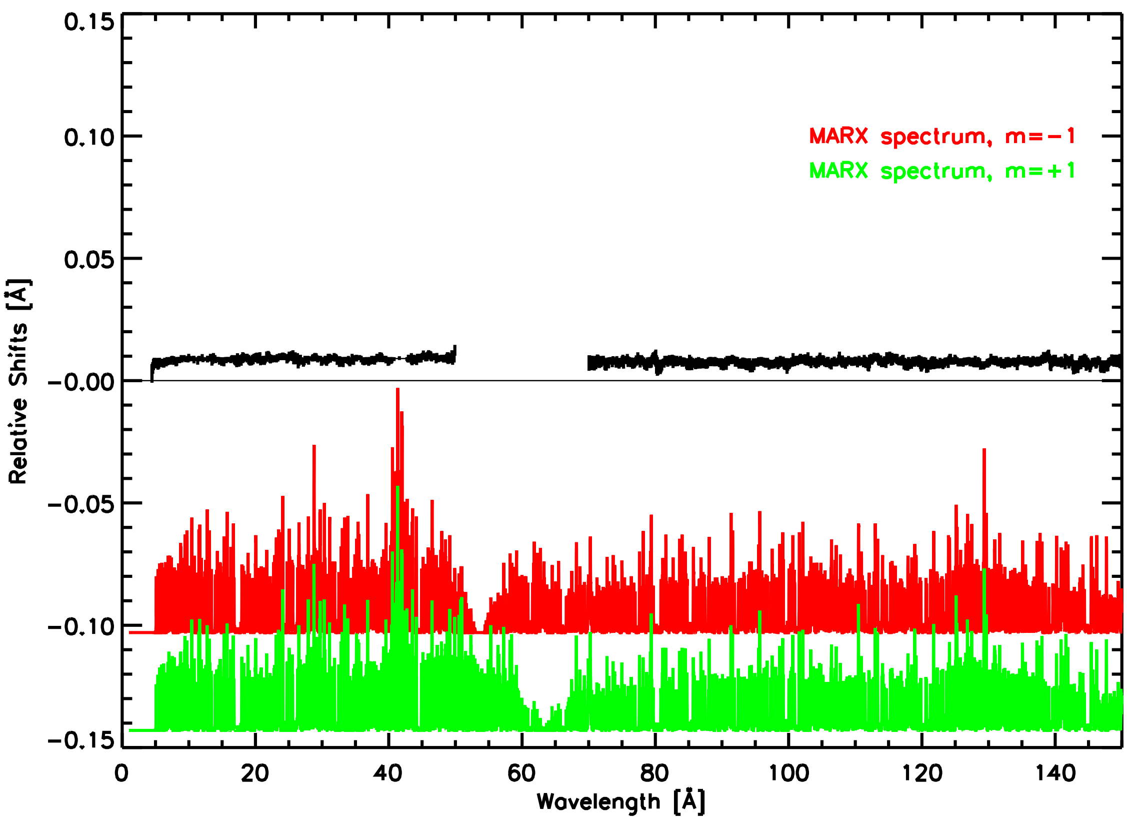
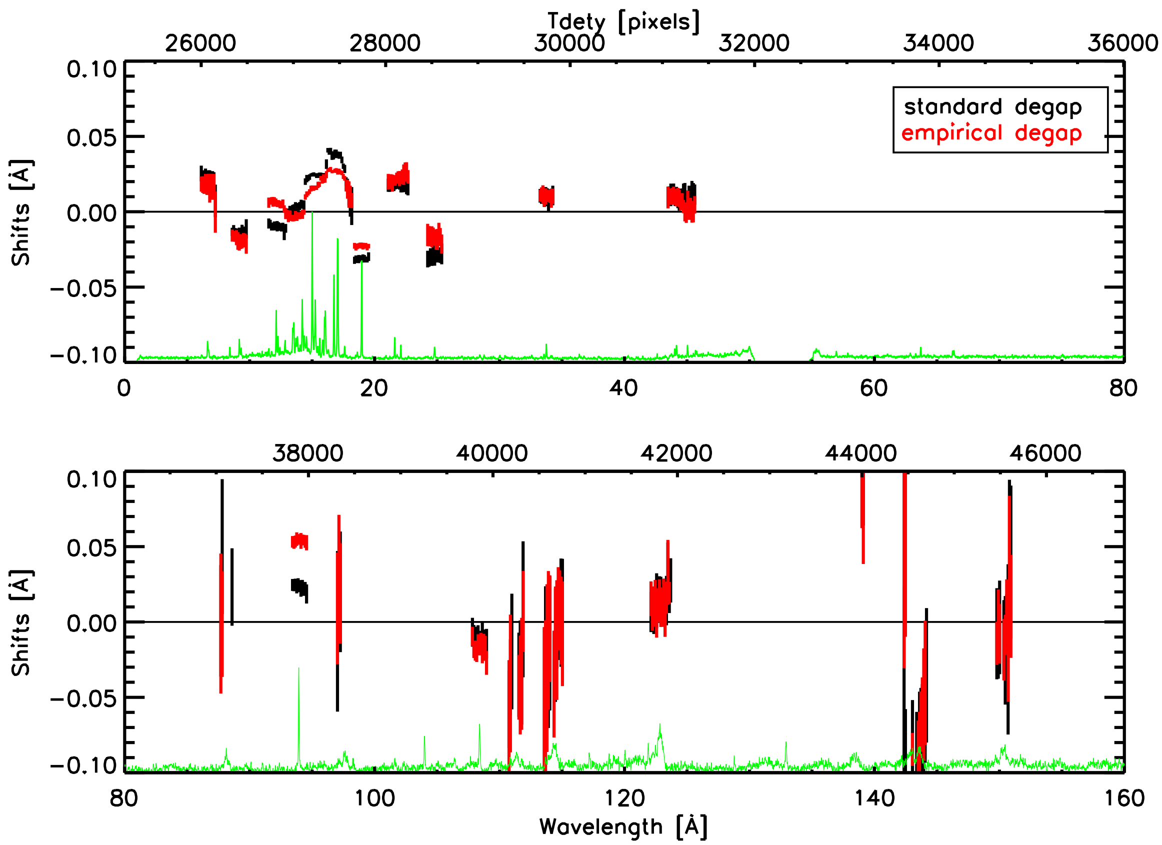


Fig. 2.— Cross-correlation of a MARX simulated negative order spectrum versus positive order spectrum. The simulated spectrum was generated with random lines and is plotted in green and red (positive and negative orders) below the results from the cross-correlation, on an arbitrary scale. Note that as expected, the cross-correlation analysis does not find any distortions in the simulated spectra, unlike in real data.



Tdety [pixels]
26000
28000
30000
32000
34000
36000
standard degap
empirical degap
Shifts [Å]
0.10
0.05
0.00
−0.05
−0.10
0
20
40
60
80
38000
40000
42000
44000
46000
Shifts [Å]
0.10
0.05
0.00
−0.05
−0.10
80
100
120
140
160
Wavelength [Å]

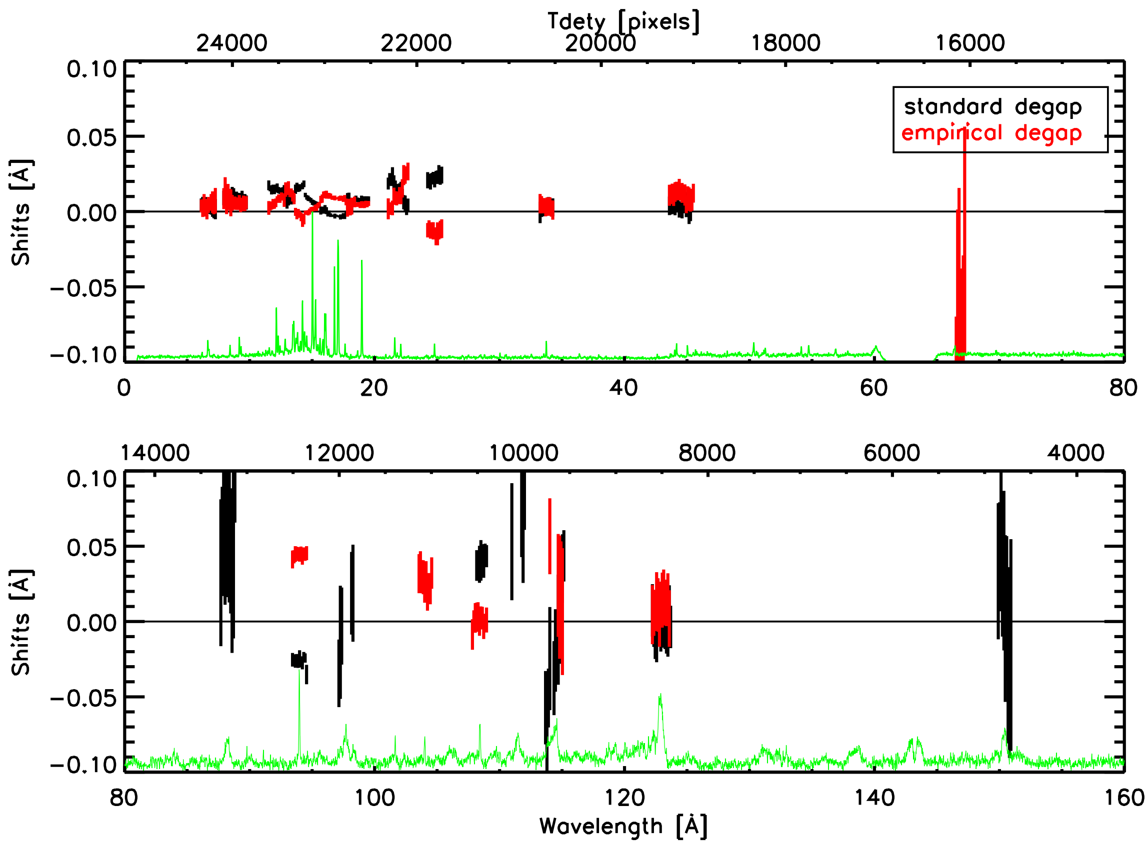


Fig. 3.— Relative wavelength non-linearities between two spectra (in both the positive (lower plot) and negative (upper plot) orders) which were obtained from different phases of the dither in the dispersion direction such that at any wavelength the two spectra originate from events that are separated on the detector by ~ 300 pixels. Plotted in black are the wavelength shifts observed among spectra that were processed with the standard HRC-S Degap map, and in red we show wavelength shifts of spectra processed with the new empirically derived degap map. In most regions, data show that applying the new degap map improves the observed non-linearities. Plotted in green is a spectrum that has been extracted from 'region 1', on an arbitrary intensity scale.

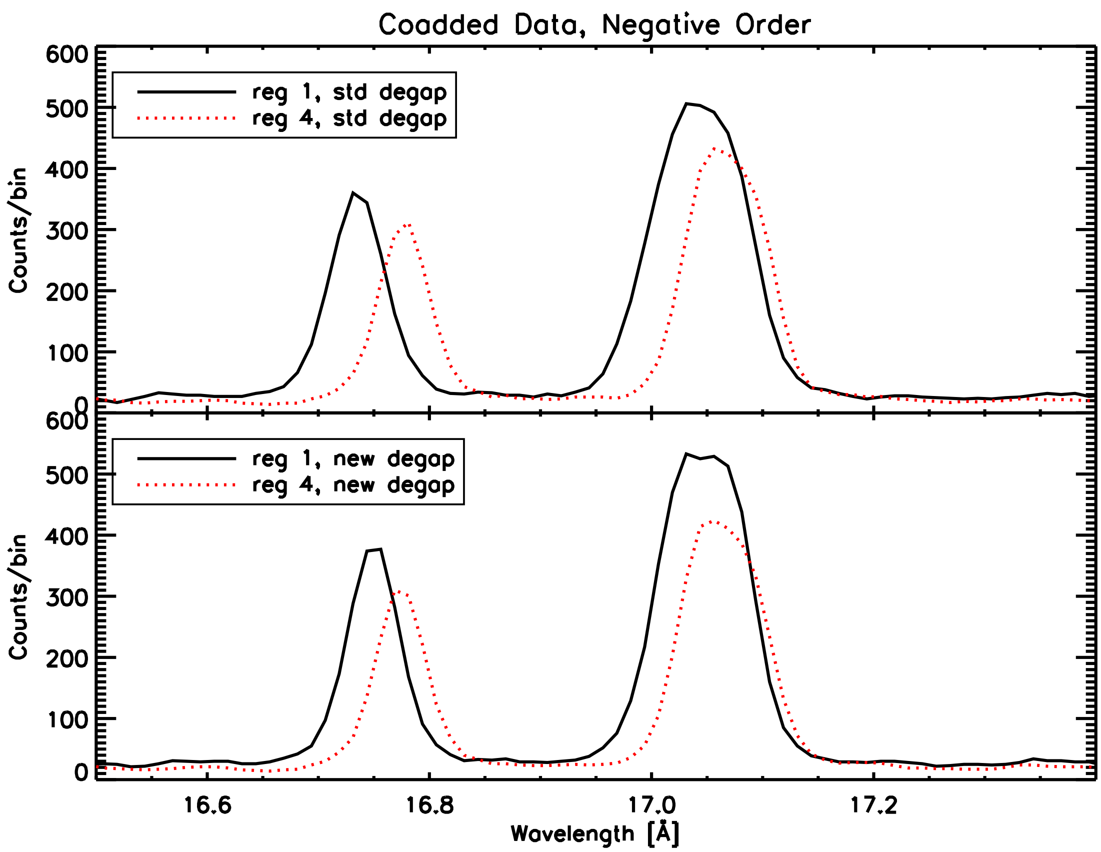
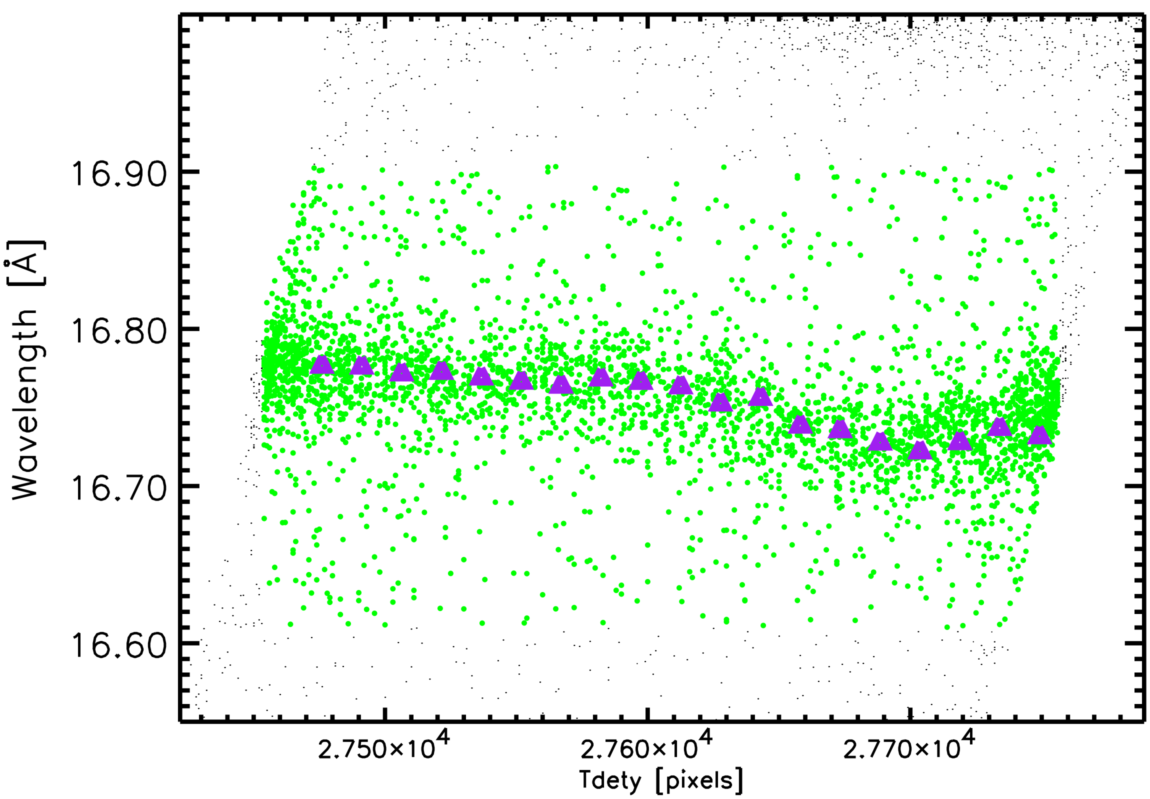


Fig. 4.— Spectra extracted from different regions along `tdety` are shown for data processed with the standard degap map (upper panel) and data processed with an empirical degap correction applied (lower panel).



16.90
16.80
16.70
16.60
Wavelength [Å]
2.750×10^4
2.760×10^4
2.770×10^4
Tdety [pixels]

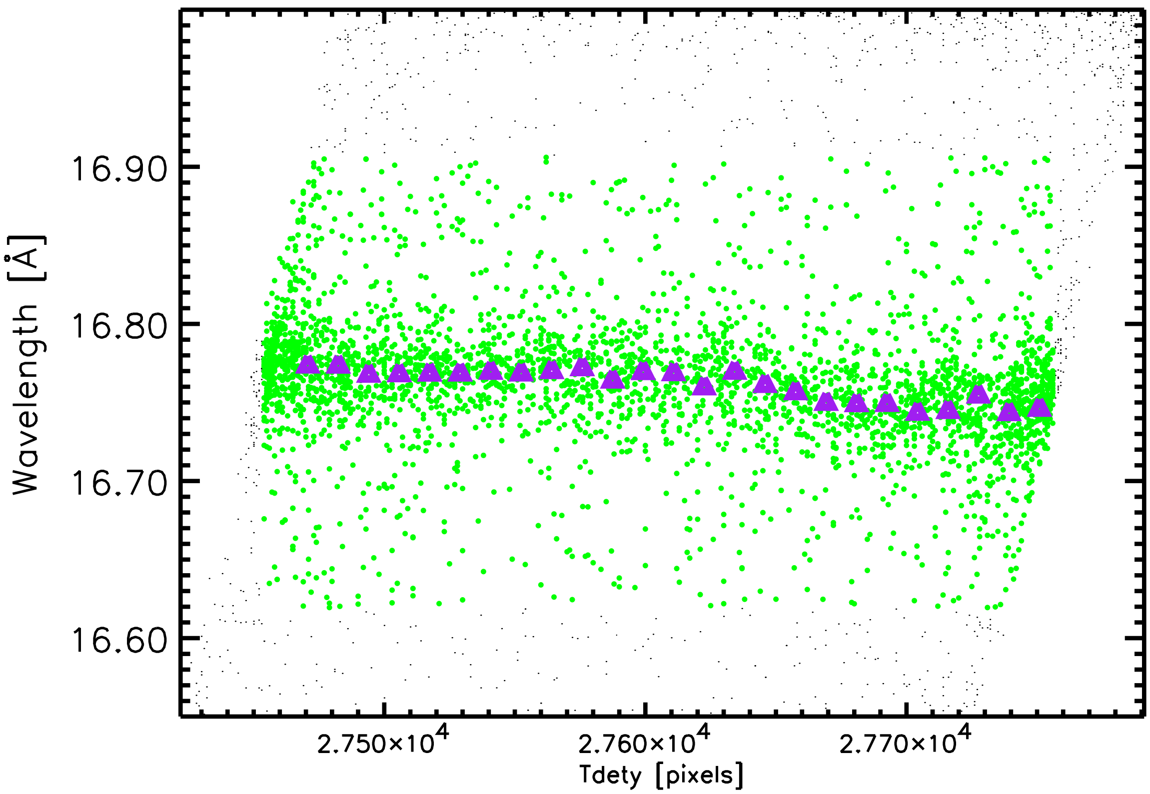
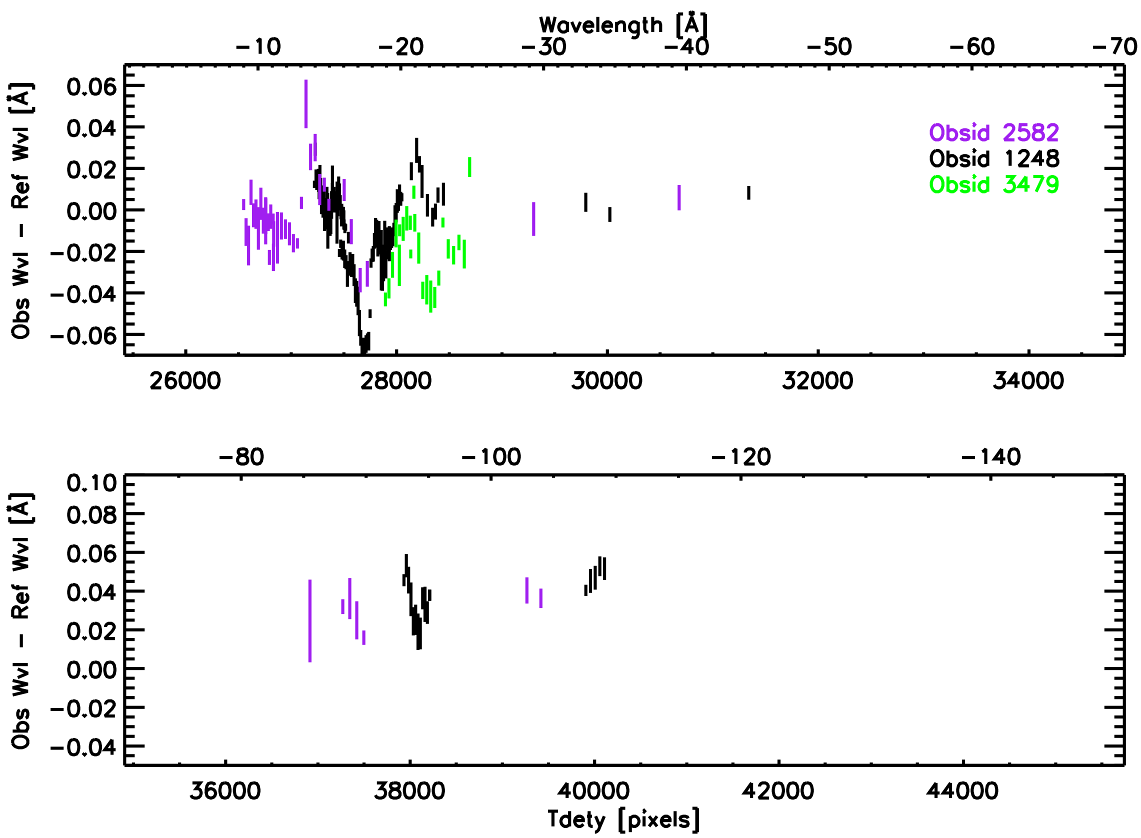


Fig. 5.— Events from the Fe XVII line of Capella (ObsID 1248) shown in **tdety**-λ space for data processed with the standard degap map (upper plot), and data with an empirical degap correction applied (lower plot). Events plotted in green were fit with modified Lorentzians to obtain the measured wavelength centroids at different `tdety` locations, which are plotted in purple. Non-linearities are clearly visible; the events 'wobble' across `tdety`, rather than forming a straight line. Non-linearities of data processed with the empirical degap correction are less obvious than for data processed without the degap correction.



Wavelength [Å]
−10
−20
−30
−40
−50
−60
−70
Obs Wvl − Ref Wvl [Å]
0.06
0.04
0.02
0.00
−0.02
−0.04
−0.06
Obsid 2582
Obsid 1248
Obsid 3479
26000
28000
30000
32000
34000
−80
−100
−120
−140
0.10
0.08
0.06
0.04
0.02
0.00
−0.02
−0.04
36000
38000
40000
42000
44000
Tdety [pixels]

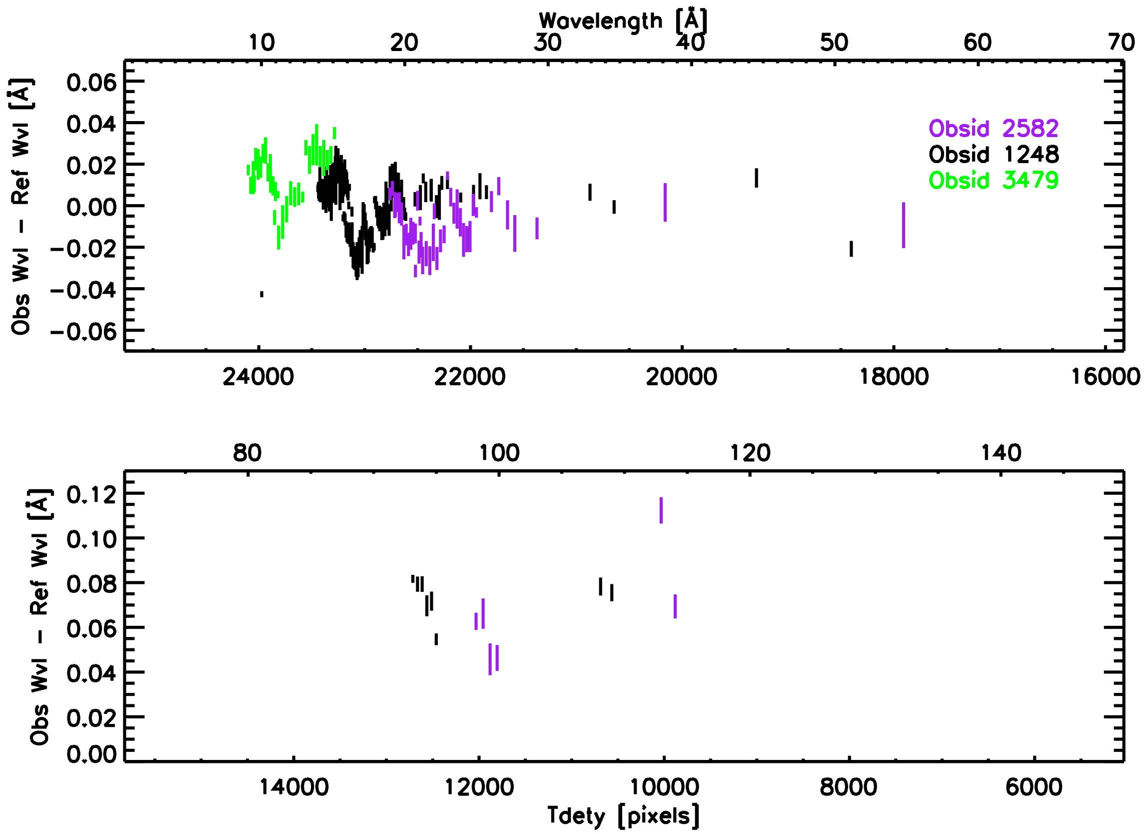


Fig. 6.— Observed versus reference wavelengths plotted as a function of `tdety`, for data processed with the standard degap map. Observed wavelengths were determined by measuring wavelength centroids along `tdety`. We have used 3 Capella observations with different offsets, to map out the non-linearities of the dispersion relation along a more extended region of the detector.