Characterizing Non−Linearities in the Chandra LETG+HRC−S Dispersion Relation

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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 the measurement of spectral lines. We also used data from a bright nova, v4743 Sagittae, whose spectrum shows many features in the 20-40Å range, where there are not as many strong lines from Capella. Using v4743 Sagittae allows us to test whether our wavelength corrections improve the non-linearities in the 20-40Å range, as well as test whether corrections derived mostly from Capella emission lines can be successfully applied to sources other than 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	2582	28.83	2002 Oct 4 23:57:53	-1.5
α Aur	3479	30.38	2002 Oct 6 10:01:58	1.5
α Aur	5041	28.88	2004 Sep 11 06:52:34	3.0
v4743 Sag	3775	25.07	2003 Mar 19 09:29:09	0

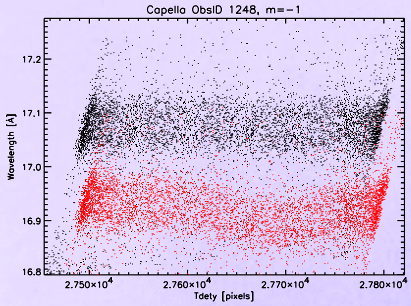


Fig. 1.— Data from Capella (ObsID 1248) shown in λ versus `tdety` space, where `tdety` is the detector dispersion axis. The original data are shown in red and the wavelength corrected data are shown in black. In red, we see that the Fe XVII emission line wobbles across the detector, its photons being mapped to different wavelengths, owing to errors in the position determination of photon events. For the corrected data (black), the events of the Fe XVII line follow a straighter line across `tdety`. (The red points have been arbitrarily offset for clarity.)

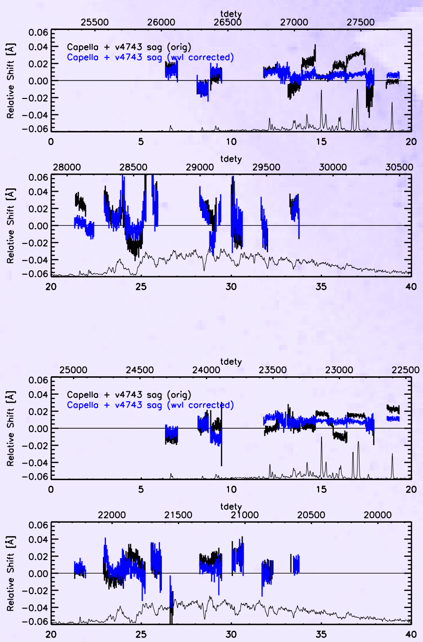


Fig. 3.— Relative wavelength shifts obtained by cross-correlating spectra extracted from different regions of the detector, where events of any given wavelength are separated by ~75 pixels. In black we show the cross-correlation results from standard processed data, and in blue we show the cross-correlation results of the wavelength corrected data, for both the negative (top) and positive (bottom) orders. Overall, the corrected data (blue) show that the non-linearities have been significantly flattened out. Overplotted in black on the bottom of each panel is the source spectrum. Note that the corrections which were derived mostly from Capella lines also flatten out non-linearities in the v4743 Sag data.

ABSTRACT

The dispersion relation for the Chandra Low Energy Transmission Grating Spectrometer (LETGS) is currently known to better than 1 part in 1000 over the wavelength range of 5-150 Å. The LETGS is primarily used with the High Resolution Camera spectroscopic array (HRC-S), which is comprised of 3 micro-channel plate (MCP) segments. In-flight calibration data observed with the LETG+HRC-S show that there are non-linear deviations in the positions of some lines by as much as 0.1 Å. These deviations are thought to be caused by spatial non-linearities in the imaging characteristics of the HRC-S detector. Here, we present the methods we used to characterize the non-linearities of the dispersion relation across the central plate of the HRC-S, and empirical corrections which drastically improve the observed non-linearities by a factor of 2 or more on the central MCP.

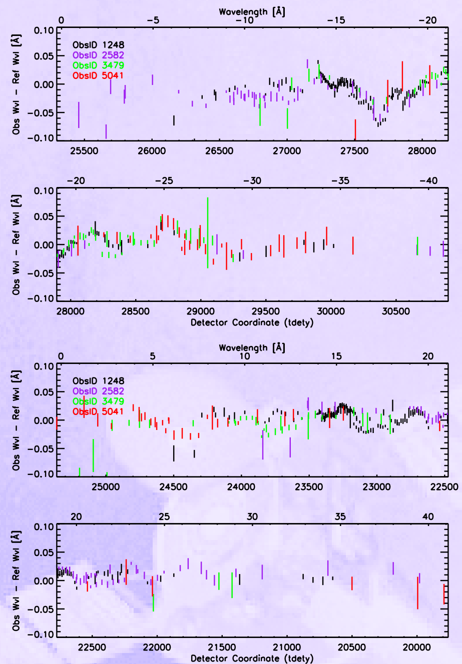


Fig. 2.— The difference in measured versus theoretical wavelengths as a function of the detector dispersion axis (`tdety`) for the negative (top) and positive (bottom) orders. We show results from 4 Capella ObsIDs, each observed with different offsets. Overall, the overlap between the data are quite good, indicating that the distortions are stable with time.

Analysis

- Examine events in λ versus `tdety` space (**Figure 1**), where `tdety` is the detector coordinate along the dispersion axis. Group 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` .
- Combine line centroiding results from all available ObsIDs and fit a spline to the measured wavelength distortions across `tdety`. Apply wavelength correction to dataset (**Figure 2**).
- The spacecraft is dithered to spread signal over a 40 arcsecond lissajous dither pattern. Extract spectra from different regions of the dither pattern (which correspond to different regions on the detector), and cross correlate by shifting one spectrum relative to the other in steps of 0.003Å and compute χ^2 at each step. Repeat process for 15 monte carlo realizations, and find the mean of the χ^2 minima for all realizations. Use cross-correlation analysis as a diagnostic to compare data before and after wavelength corrections were applied (**Figure 3**).

Summary & Future Work

- We have improved the RMS of the dispersion relation on the central plate of the HRC-S by more than a factor of 2, going from 0.012Å to 0.005Å (**Figure 4**).
- Wavelength non-linearities seen from cross-correlation analyses of spectra extracted from adjacent dither pattern regions show improvement of up to ~0.04Å (**Figure 3**).
- Line widths of many lines on the central plate of the HRC-S show drastic improvement. Measured line widths have improved by up to 25%, in some cases (**Figure 5**).
- Await further observations whose spectra have distinct line features out at longer wavelengths, and derive a more complete correction for the outer HRC-S plates, as well as the central plate.
- Merge data from cross-correlation analysis and reference line wavelength analysis to extrapolate wavelength corrections for regions of the detector which cannot be directly probed due to the absence of high signal-to-noise emission lines.
- Combine our wavelength corrections with new empirical detector "degapping".

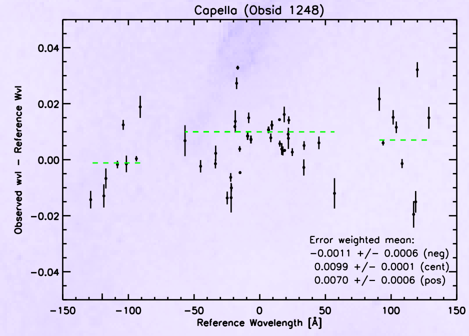
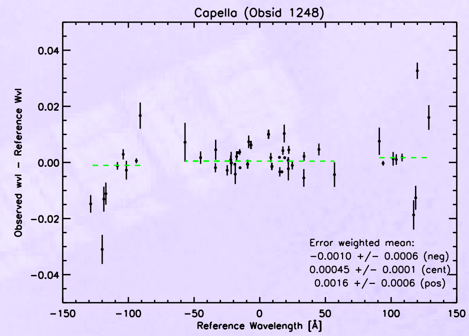


Fig. 4.— The LETG+HRC-S dispersion relation for the central micro-channel plate (MCP), based on line measurements of Capella ObsID 1248, for lines whose theoretical wavelengths are accurately known. There are clear non-linearities, particularly noticeable in the negative order. The root-mean-square (RMS) of these data points is 0.012Å. A dashed green line is drawn through the error-weighted mean. The lower plot shows the dispersion relation based on line measurements of the same data after our empirical correction has been applied. The RMS has decreased to 0.005Å and the non-linearities have flattened out significantly.



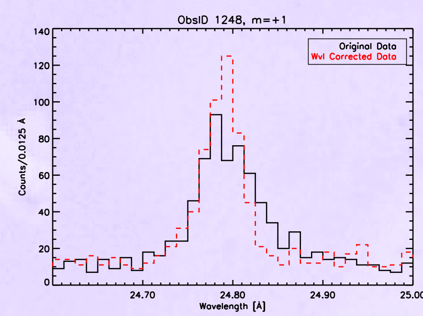
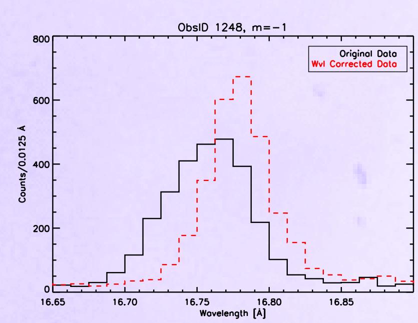


Fig. 5.— Line profiles shown for the original data (black) and wavelength corrected data (red). The line profiles of the wavelength corrected data show much narrower line widths with sharper peaks.



References

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Acknowledgments

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