The LETGS Dispersion Relation and the Accuracy of Chandra Velocity Studies

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1. New plate gap calibration
2. Impact of empirical HRC-S degap on dispersion relation non-linearities
3. How accurately can we measure velocities with Chandra gratings?
   ▪ HETGS examples
XRCF Plate Gap Calibration (M. Juda)

- Geometry of finite thickness HRC-S plates --> position error
- Additional correction arises from different LETG+HRC-S disp rel cf that known at XRCF

Residual slope
Dispersion Relation Post-Bug Fix

- Clarified apparent plate gap problem
  - Non-linearities not affected
Verification with ACIS-S

ObsID 55 (Observed 11/99, Orb Phase 0.86)
New Plate Gap Calibration

- Removes discontinuities between plates
  - Resulting RMS deviation=0.013 AA (~0.01% @100AA)
Mapping HRC-S Spatial Non-Linearity

- Examine events from bright well-understood lines in detector coordinates (tdet y)
  - BUT: Relatively few bright lines - poor coverage
- Cross-correlate spectra in small wavelength intervals extracted from different dither phases
  - At any given wavelength, maps out relative position error between areas of the detector 1 mm apart.
  - Effective for any spectra with significant structure; does not require “high quality” lines.
Mapping Non-Linearity in $t_{dety}$

$T_{dety} [\text{pixels}]$

Wavelength [Å]
Mapping Non-Linearity in t deity
Mapping HRC-S Spatial Non-Linearity

- Examine events from bright well-understood lines in detector coordinates (tdet y)
  - **BUT**: Relatively few bright lines - poor coverage
- Cross-correlate spectra in small wavelength intervals extracted from different dither phases
  - At any given wavelength, maps out relative position error between areas of the detector ~1mm apart.
  - Effective for any spectra with significant structure; does not require “high quality” lines.
Mapping HRC-S Detector Non-Linearities

- Examine events from bright well-understood lines in detector coordinates ($t_{\text{det}}$, $y$)
  - BUT: Relatively few bright lines - poor coverage
- Cross-correlate spectra in small wavelength intervals extracted from different dither phases
  - At any given wavelength, maps out relative position error between areas of the detector ~1mm apart.
  - Effective for any spectra with significant structure; does not need “high quality” lines
Dither-Split Cross-Correlation

Eg extract spectra for times when source is here and here.
Dither-Split Cross-Correlation

\begin{center}
\begin{tabular}{|c|c|c|c|c|c|c|c|}
\hline
Tdet [pixels] & 26000 & 28000 & 30000 & 32000 & 34000 & 36000 \\
\hline
Shifts [Å] & \multicolumn{6}{c|}{LETG+HRC-S -ve orders} \\
\hline
\end{tabular}
\end{center}

\begin{center}
\begin{tabular}{|c|c|c|c|c|c|c|}
\hline
Wavelength [Å] & 80 & 100 & 120 & 140 & 160 \\
\hline
Shifts [Å] & \multicolumn{5}{c|}{\textit{letg+hrc-s -ve orders}} \\
\hline
\end{tabular}
\end{center}
Testing an Empirical Degap

- Is non-linearity caused by degap deficiencies?
- Empirical degap correction derived for “dispersion strip” of HRC-S based on bright continuum source (PKS 2155-304)
  - Vinay’s talk
- Applied to Capella observations
  - Analysed using cross-correlation and tety techniques
Dither-Split Cross-Correlation

Vast improvements!!

But...
How accurately can we measure velocities with Chandra?

- Provided line profile is adequately sampled, centroid accuracy in principle depends only on S/N
- BUT: at some level, other systematics will dominate
  - Line blends
  - Detector imperfections
  - Optical bench stability
  - Aspect error
  - etc
Capella: Wavelength Calibration Standard

G1III + G8III

- 108 day orbital period
- Projected orbital speed \( \sim 25 \text{ km/s} \)
- G1 8 day spin period
  - Equatorial velocity \( \sim 36 \text{ km/s} \)

QuickTime® and a YUV420 codec decompressor are needed to see this picture.
HETGS (MEG) Dispersion Relation

Based on “unblended” lines with accurately-known wavelengths

ObsId 1103 (Observed 9/99, Orb Phase 0.40)

Capella (G1III+G8III)

0th order centroid determined by +/- cross-correlation
HETGS (MEG) Dispersion Relation

Based on “unblended” lines with accurately-known wavelengths

ObsID 57 (Observed 3/00, Orb Phase 0.96)

Capella (G1III+G8III)

0th order centroid determined by +/- cross-correlation
HETGS (MEG) Dispersion Relation

Based on “unblended” lines with accurately-known wavelengths

ObsID 1010 (Observed 2/01, Orb Phase 0.27)

Capella (G1III+G8III)

0th order centroid determined by +/- cross-correlation
HETGS (MEG) Dispersion Relation

Based on "unblended" lines with accurately-known wavelengths

ObsID 2583 (Observed 4/02, Orb Phase 0.52)

Capella (G1III+G8III)

0th order centroid determined by +/- cross-correlation
HETGS (MEG) Dispersion Relation

Based on “unblended” lines with accurately-known wavelengths

ObsID 3674 (Observed 9/03, Orb Phase 0.48)

Capella (G1III+G8III)

0th order centroid determined by +/- cross-correlation
Algol (B8V + K2 III)

X-ray dark

Roche-lobe filling, coronally active

Period = 2.8d; secondary orbital speed ~ 180 km/s
Algol (B8V + K2III)

- 2.8 day orbital period
- 180 km/s orbital speed
Algod Cross-Correlation Analysis

Use all of MEG spectra of Algod vs Capella - greatly increase S/N

Statistical uncertainties as low as 10 km/s
Comparing Observed FWHM and RMF

Capella FWHM in fairly good agreement with RMF

Evidence for excess Line width in Algol

Orders: - sum +
Algor Line Profiles

~100 km/s extra Broadening required
Conclusions

RMS deviations in LETG+HRC-S now down to 0.013 AA

- Have tools to probe dispersion non-linearity
- In-flight degap helps but does not solve the problem
- Cross-correlation techniques permit potentially very accurate velocity studies (~10 km/s)
- BUT systematics seem to dominate at 20-30 km level