Using Standard Candle X-ray spectra to calibrate the strongly variable MOS response

“Calibration or just a *mathematical* exercise?”

Ties together three themes....

1) Computationally quick phenomenological RMF model
2) Derivation of RMF model parameters via optimisation algorithm
3) Use of “standard candle” spectra to constrain RMF solution
Changes in the MOS redistribution: increased redistribution from higher to lower energies.

The INS RX J0720-3125

The O star Zeta Puppis
Changes in the MOS redistribution: increased redistribution from higher to lower energies.

The INS RX J0720-3125

The O star Zeta Puppis

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IACHEC 12/04/10
1ES0102
0.1-0.35 keV images

~ 1 arcminute off-axis

~ 1 arcmin

~ On-axis
1ES0102
0.1-0.35 keV images

~ 1 arcminute off-axis

~ On-axis
Patch position and dimensions seem to “correlate” with accumulated number of detected source photons.

2005 Numbers
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MOS Response:

3 RMF regions
0”-15”, 15”-40”, >40”
MOS Response:

- 3 RMF regions
  - 0”-15”, 15”-40”, >40”
- 2 Instruments
- 9 Epochs

= 54 parameter files!

PSF (rmfgen default) or flat weighting to create average RMF (automatically generated in SAS)
Current Empirical Surface Loss Model

\[ E(z) = f(z) \, E_0 \]
\[ f(z) = \alpha + (\beta \, E_0) \]
\[ I(e,E_0) = \sum I(E_0,z) \, G(e,E(z),\sigma) \, dz \]
\[ \alpha = \alpha(E_0), \, \beta = \beta(E_0) \]
Frac in (red+orange) = 0.48
Frac in orange = 0.52

“core (0”-15”)”

Frac in (red+orange) = 0.44
Frac in orange = 0.23

Out of patch

Frac in (red+orange) = 0.53
Frac in orange = 0.55

“wings (15”-40”)”

New model avoids the time consuming integration and describes the rmf by various mathematical shapes.

Evaluation time for 2400 x 2400 array (5eV binning) ~ 3.5 seconds in IDL
Parameters which define redistribution matrix, $R$, have simple functions with energy.

Resolution $= \alpha_1 + \beta_1 \times \sqrt{e0}$

$F_{\text{Loss}} = \alpha_2 \exp\left(\frac{-\left(e0 - \beta_2\right)}{\gamma_2}\right)$ for $\beta_2 > e0$

$= \alpha_2$

$\beta_2 \leq e0$

$F_{\text{Loss}} = F_{\text{Loss}_\text{peak}} + F_{\text{Loss}_\text{shelf}}$

$F_{\text{Loss}_\text{peak}} = \alpha_3 \exp\left(\frac{-\left(e0 - \beta_3\right)}{\gamma_3}\right)$ for $\beta_3 > e0$

$= \alpha_3$

$\beta_3 \leq e0$
Basic Scheme: For a given epoch and spatial region, take set of standard spectra, $S^1, S^2, \ldots, S^n$

\[ D_i^1 = N^1 \sum R_{ij} A_{j}^1 S_{j}^1 \]
\[ D_i^2 = N^2 \sum R_{ij} A_{j}^2 S_{j}^2 \]
\[ \ldots \]
\[ D_i^n = N^n \sum R_{ij} A_{j}^n S_{j}^n \]

Adjust parameters (using tnmin algorithm) which define rmf, $R$, and global normalisations, $N$, to minimise

\[ \sum \frac{(O_{i}^1 - D_{i}^1)}{\delta O_{i}^1}^2 + \sum \frac{(O_{i}^2 - D_{i}^2)}{\delta O_{i}^2}^2 + \ldots + \sum \frac{(O_{i}^n - D_{i}^n)}{\delta O_{i}^n}^2 \]
“Standard Candle” Spectral Models

1) The white dwarf CAL83

2) The isolated neutron star RXJ 1856

3) The O star Zeta Puppis

4) The SNR 1ES0102
“Standard Candle” Spectral Models

1) The white dwarf CAL83

   See next slides

2) The isolated neutron star RXJ 1856

   \texttt{phabs \ast (bb + bb)} \quad \text{(V. Burwitz pn model)}

3) The O star Zeta Puppis

   Frank Haberl’s RGS model

4) The SNR 1ES0102

   The IACHEC WG model (Plucinsky et al.)

Non-LTE Model atmosphere derived from LETG and RGS (Rev 0068)

Model file converted to atable model

$n_H = 6.5 \times 10^{20} \text{ cm}^{-2}$ (abund *wilm*)
Example Epoch: Revolution 0795-0900

On-axis, “patch affected”

Standards:

RXJ1856 (Rev 878)
Puppis (Rev 795)
1E0102 (Rev 894-900)

Test Sources:

H1426 (BL Lac) (Rev 939)
**“Wings”**

**RXJ1856 MOS1 Rev 0878 Thin**

<table>
<thead>
<tr>
<th>Energy (keV)</th>
<th>Normalized Counts s⁻¹ keV⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1 - 0.2</td>
<td>0.817 - 0.906</td>
</tr>
<tr>
<td>0.5</td>
<td>3.994 - 1.058</td>
</tr>
</tbody>
</table>

**RXJ1856 MOS2 Rev 0878 Thin**

<table>
<thead>
<tr>
<th>Energy (keV)</th>
<th>Normalized Counts s⁻¹ keV⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1 - 0.2</td>
<td>0.962 - 0.985</td>
</tr>
<tr>
<td>0.5</td>
<td>2.846 - 1.344</td>
</tr>
</tbody>
</table>

**Puppis MOS1 Rev 0795**

<table>
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<th>Energy (keV)</th>
<th>Normalized Counts s⁻¹ keV⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1 - 0.2</td>
<td>1.029 - 1.035</td>
</tr>
<tr>
<td>0.5</td>
<td>1.298 - 1.214</td>
</tr>
</tbody>
</table>

**Puppis MOS1 Rev 0795**

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<th>Energy (keV)</th>
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</tr>
</thead>
<tbody>
<tr>
<td>0.1 - 0.2</td>
<td>1.073 - 1.071</td>
</tr>
<tr>
<td>0.5</td>
<td>1.298 - 1.216</td>
</tr>
</tbody>
</table>
4 Obs of 1E0102 in raster around boresight.
The images show spectroscopic analysis of XMM-EPIC MOS data for two energy bands: "Core" (1.325 - 1.173) and "Wings" (4.728 - 1.713) for MOS1 (Rev 0894-0900) and 1E0102 MOS2 (Rev 0894-0900). The analysis includes normalized counts per second per keV, with black representing the current RMF and red representing the new RMF. The sign of the data modeled by each RMF is also shown.
H1426 PN/MOS1 Rev 0939

Black (PN) Red (MOS1 old RMF)

0.996
1.065

H1426 PN/MOS1 Rev 0939

Black (PN) Red (MOS1 new RMF)

1.000
1.059

H1426 PN/MOS2 Rev 0939

Black (PN) Red (MOS2 old RMF)

1.036
1.010

H1426 PN/MOS2 Rev 0939

Black (PN) Red (MOS2 new RMF)

1.033
0.987

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Conclusions:

1) The MOS has a strongly variable on-axis response and needs to calibrated against “something” given that we have no physical model of the response which explains the changes we see.

2) The best we can do is probably pick models of astrophysical sources for which there is some consensus within the community of what these models should be....i.e. so-called “standard candles”

3) We have a mathematical model of the response which looks to give a good fit to a chosen subset of these “standard candles”

4) If we adopt this route we need to make the ALL the “standard candle” models publically available to the community (i.e. XSPEC xcm files) with documentation as to how these models were derived.