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
Basic Scheme: For a given epoch and spatial region...

\[ D_i^1 = N_1 \sum R_{ij} A_j^1 S_j^1 \]
\[ D_i^2 = N_2 \sum R_{ij} A_j^2 S_j^2 \]
\[ \ldots \]
\[ D_i^n = N_n \sum R_{ij} A_j^n S_j^n \]

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

\[ \sum \left( \frac{(O_i - D_i)}{\delta O_i} \right)^2 + \sum \left( \frac{(O_i - D_i)}{\delta O_i} \right)^2 + \ldots + \sum \left( \frac{(O_i - D_i)}{\delta O_i} \right)^2 \]
Previous Phenomenological Model: The VRMF Model

Blue Wing: Gaussian

Red Wing: Voigt Function

= Gaussian convolved with a Lorentian.

Dampening factor
= 0 (Gaussian)
> 0 (Lorentz-like)
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”)”

Frac in (red+orange) = 0.48
Frac in orange = 0.52

“core (0”-15”)”

New model adds a flat “shelf”

Evaluation time for 2400 x 2400 array (5eV binning) ~ 3.5 seconds in IDL
Parameters which define redistribution matrix, \( R \)

Resolution \( = \alpha_1 + \beta_1 \times \sqrt{e_0} \)

Dampen\( = \alpha_2 \exp\left( \frac{-(e_0-\beta_2)}{\gamma_2} \right) \) for \( \beta_2 > e_0 \)
\( = \alpha_2 \) \( \beta_2 \leq e_0 \)

i.e. tends to zero for large \( e_0 \) (more Gaussian)
\[ F_{\text{Loss}} = \alpha_3 \exp\left( -\frac{(e_0 - \beta_3)}{\gamma_3} \right) \quad \text{for } \beta_3 > e_0 \]
\[ = \alpha_3 \quad \beta_3 \leq e_0 \]

\[ F_{\text{Loss}} = F_{\text{Loss\_peak}} + F_{\text{Loss\_shelf}} \]

\[ F_{\text{Loss\_peak}} = \alpha_4 \exp\left( -\frac{(e_0 - \beta_4)}{\gamma_4} \right) \quad \text{for } \beta_4 > e_0 \]
\[ = \alpha_4 \quad \beta_4 \leq e_0 \]

\[ E_{\text{Loss}/e_0} = \alpha_5 \quad \text{for } e_0 < 300 \text{ eV} \]
\[ = \alpha_6 \quad \text{for } e_0 > 400 \text{ eV} \]
Total parameters = 13

Not counting parameters giving intensity of silicon fluorescence and escape peaks (fixed to previous calibration)

Time to derive one solution for a given set of input spectra ~ 3 to 6 hours.
“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

   \( \text{phabs} \ast (\text{bb} + \text{bb}) \) (V. Burwtiz pn model)

3) The O star Zeta Puppis

   Frank’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

\[ n_H = 6.5 \times 10^{20} \text{ cm}^{-2} \text{ (abund wilm)} \]

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

Model file converted to atable model

$n_H = 6.5 \times 10^{20} \text{ cm}^{-2} \text{ (abund wilm)}$

Use instead best fit *descriptive* model to PN = phabs * bb (abund wilm)

$n_H = 1.11 \times 10^{21} \text{ cm}^{-2}$

$kT = 0.034 \text{ keV}$
Epoch 1: Revolution 0065 - 0156

“Pre-Patch”

Standards:

1E0102 (Rev 65)
Cal 83 (Rev 68)
Puppis (Rev 156)

Test Sources:

MS0737 (BL Lac) (Rev 63)
3C 273 (Blazar) (Rev 94)
M1

Black (thin) Red (med) Green (thick)

<table>
<thead>
<tr>
<th>Energy (keV)</th>
<th>Normalized counts s^{-1} keV^{-1}</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2</td>
<td>1.222</td>
</tr>
<tr>
<td>0.3</td>
<td>1.198</td>
</tr>
<tr>
<td>0.4</td>
<td>1.234</td>
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<tr>
<td>0.5</td>
<td>1.750</td>
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</table>

M2

Black (thin) Red (med) Green (thick)

<table>
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<tr>
<th>Energy (keV)</th>
<th>Normalized counts s^{-1} keV^{-1}</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2</td>
<td>1.293</td>
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<tr>
<td>0.3</td>
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<tr>
<td>0.4</td>
<td>1.251</td>
</tr>
<tr>
<td>0.5</td>
<td>1.482</td>
</tr>
</tbody>
</table>

Steve Sembay (sfs5@star.le.ac.uk)
Madrid 23/03/10

Wednesday, 24 March 2010
Black (PN) Red (MOS1 old RMF) 1.147 1.093
Black (PN) Red (MOS1 new RMF) 1.141 1.094
Black (PN) Red (MOS2 old RMF) 1.057 1.135
Black (PN) Red (MOS2 new RMF) 1.053 1.129

Energy (keV) 0.01 0.1 1
normalized counts s⁻¹ keV⁻¹
sign(data-model) × Δχ²
Steve Sembay (sfs5@star.le.ac.uk)
Madrid 23/03/10

Wednesday, 24 March 2010
Epoch 2: 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)
Steve Sembay (sfs5@star.le.ac.uk)
Madrid 23/03/10

Wings

RXJ1856 MOS1 Rev 0878 Thin
Black (current RMF) Red (new RMF)

0.817 - 0.906
3.994 - 1.058

RXJ1856 MOS2 Rev 0878 Thin
Black (current RMF) Red (new RMF)

0.962 - 0.985
2.846 - 1.344

Puppis MOS1 Rev 0795
Black (current RMF) Red (new RMF)

1.029 - 1.035
1.298 - 1.214

1.073 - 1.071
1.298 - 1.216

Wednesday, 24 March 2010
“Core”

1.325 - 1.173

“Wings”

4.728 - 1.713

2.060 - 2.121

6.582 - 1.836

Steve Sembay (sfs5@star.le.ac.uk)
Madrid 23/03/10
Epoch 3: Revolution 1265-1335

Off axis (Still on CCD1)

Standards:

1E0102 (Rev 1265)
RXJ1856 (Rev 1335)

Test Sources:

REJ 2248 (AGN) (Rev 1361)
XMM EPIC MOS

Steve Sembay (sfs5@star.le.ac.uk)
Madrid 23/03/10

Wednesday, 24 March 2010
Epoch 4: Revolution 1616-1636

On-axis, “patch affected”

Standards:

RXJ1856 (Rev 1616)
1E0102 (Rev 1636)

Test Sources:

3C 273 (BL Lac) (Rev 1649)
Steve Sembay (sfs5@star.le.ac.uk)
Madrid 23/03/10

0.821 - 0.975
18.13 - 2.495

0.892 - 0.894
28.09 - 7.000

1.955 - 1.770

1.560 - 1.874

Wednesday, 24 March 2010
"Wings"

Steve Sembay (sfs5@star.le.ac.uk)
Madrid 23/03/10

XMM
EPIC
MOS

Wednesday, 24 March 2010
Wednesday, 24 March 2010

Steve Sembay (sfs5@star.le.ac.uk)
Madrid 23/03/10
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.
End