XRT Point Spread Function

- Shifts in PSF position with energy
- King + Gaussian profile fitting
  - Off-Axis PSF
  - Timing mode PSF
Examples of King profile fits to narrow-band images

MCG-6-30-15

\begin{align*}
\text{Normalization} &= 168.14170 \\
\text{CoreRadius} &= 4.2704500 \\
\text{SlopeAlpha} &= 1.4157674
\end{align*}

\begin{align*}
\text{Normalization} &= 715.39377 \\
\text{CoreRadius} &= 5.2207406 \\
\text{SlopeAlpha} &= 1.5469457
\end{align*}

MOS1
Rev 303
6 keV

PN
Rev 301
3 keV

Andy Read (amr30@star.le.ac.uk)
EPIC CAL/OPS Meeting
MPE, Germany 04-05/05/06
New XRT PSF CCFs yield consistent spectral parameters as a function of extraction radius.
XRT Point Spread Function

• Shifts in PSF position with energy
- Lines show shift in PSF centroid position with increasing energy (※ = lowest energy)
- Shifts are small << 1 arcsec in most cases
- Stats not very good at highest energies (some larger shifts suggested)
XRT Point Spread Function

- King + Gaussian profile fitting
PSF King+Gaussian [KG] Fitting

- King fits sometimes underestimate the PSF profile at the very centre

\[
\text{PSF}_{KG}(r) = \frac{A}{[1+(r/r_0)^2]} + Be^{-Cr^2}
\]

\[\uparrow\quad \uparrow\]

KING + GAUSSIAN

- Would require new software [CAL, arfgen etc…]
Example:
MOS2 - Rev 301 (MCG-06-30-15)
0.225 keV
King fit

\[ \begin{align*}
K \text{Norm} &= 321.34614 \pm 4.9851555 \\
K \ r_0 &= 4.0609674 \pm 0.67138133 \\
K \alpha &= 1.4165812 \pm 0.0087229667
\end{align*} \]
Example:
MOS2 - Rev 301 (MCG-06-30-15)
0.225 keV
King + Gaussian fit
PSF King+Gaussian [KG] Fitting

- e.g. M1 100 eV
- Substantial Gaussian component allowed (ratio of normalizations 25±1%)
PSF King+Gaussian [KG] Fitting

- e.g. PN 3000 eV
- Very small (~0) Gaussian component required (ratio of normalizations 1±1%)
- PN’s larger pixels insensitive to the very core of the PSF
PSF King+Gaussian [KG] Fitting

- Ratio of normalizations [Gauss/King] versus Energy
- M1/M2: Significant Gauss component allowed, especially at low/medium-E – [no Gauss component required at high-E]
- PN: No Gauss component required (except perhaps at lowest-E [1.8±0.6%])
PSF King+Gaussian [KG] Fitting

- Comparison of present CCF PSF and KG PSF

- M1 100eV
- Effective area @ 25'' increases by 0.5%

XMM EPIC MOS

Andy Read (amr30@star.le.ac.uk)
EPIC CAL/OPS Meeting
MPE, Germany 04-05/05/06
PSF King+Gaussian [KG] Fitting

- Comparison of present CCF PSF and KG PSF
- M2 3000eV
- Effective area @ 25 increases by 0.8%

Unsure as yet as to changes to any spectral analysis results (using arfgen)
PSF King+Gaussian [KG] Fitting

- Comparison of AMR1 PSF and KG PSF
- PN 3000eV
- Effective area @ 25 decreases by 0.9%
- Unsure as yet as to changes to any spectral analysis results (using arfgen)
XRT Point Spread Function

- Off-Axis PSF
A few suitable off-axis sources are now appearing in the XMM archive.

SLX 1744-299
~ 4 arcmin

SLX 1744-300
~ 1.5 arcmin

X-ray bursters
SLX 1744-299

~ 4 arcmin

M1 Low-E

M2 Low-E

PN Low-E

M1 High-E

M2 High-E

PN High-E
- Variations of R0 (King core radius) and (King slope) with energy
- Different behaviour from e.g. MCG-06-30-15 (on-axis, black points – used for CCF)

Note: PSF parameters used (partly) to determine the PSF show some scatter at high-energy
Can plot off-axis PSFs and compare with on-axis CCF PSFs

Off-axis PSFs are ~wider, flatter, more extended

Can calculate enclosed energy as a function of energy...
PSF parameters not very well determined at high-energy
However, Source is quite piled-up!
- Need to investigate less piled-up sources
NGC7603   10 arcmin off-axis
AX J1746.3-2843  5.5 arcmin off-axis  ~ 30ksec
Andy Read (amr30@star.le.ac.uk)
EPIC CAL/OPS Meeting
MPE, Germany 04-05/05/06
Source is very hard –
No information below ~2keV, but can obtain high-energy PSFs
- Again, different behaviour from on-axis PSFs
Enclosed Energy as Function of Energy

Enclosed energy fraction within 25 arcseconds

Energy (eV)

0.90
0.85
0.80
0.75
0.70
0.65

2.0×10^3 4.0×10^3 6.0×10^3 8.0×10^3 1.0×10^4 1.2×10^4

MOS1
CCF On-Axis
Rev 0143 [5.5']
CCF Off-Axis [5.5']
Source is not particularly piled-up
Source is very slightly extended? – added complication
QSO 1308+326  7 arcmin off-axis  ~50 ksec clean FF data
The image contains two graphs showing the relationship between energy (keV) and certain parameters labeled as \( R[\text{Param 1}] \) and \( \alpha[\text{Param 2}] \). The data points are distinguished by different markers and symbols for different categories, such as M1 301, M1 302, M1 303, and M1 QSO Rev 550.

- **Graph 1 (Top):**
  - \( R[\text{Param 1}] \) vs. Energy (keV)
  - Categories: M1 301 (filled circle), M1 302 (filled square), M1 303 (filled diamond), M1 QSO Rev 550 (open circle)

- **Graph 2 (Bottom):**
  - \( \alpha[\text{Param 2}] \) vs. Energy (keV)
  - Categories: M1 301 (filled circle), M1 302 (filled square), M1 303 (filled diamond)

These graphs are likely from a presentation or report related to EPIC CAL/OPS Meeting at MPE, Germany, dated 04-05/05/06.
Enclosed Energy as Function of Energy

Enclosed energy fraction within 25 arcseconds

Energy (eV)

- MOS1
- CCF On-Axis
- Rev 0550 [7']
- CCF Off-Axis [7']
Source is not piled-up
Source is not extended

PSF parameters not very well determined at high-energy
Related point 1 - PSF uncertainties at high-E
- room for manoeuvring?

- Energy dependence of PSF is ~flat out to ~10keV
- Beyond this, it appears to steepen sharply
- In-orbit determination of the PSF is not very good >~ 10 keV (no suitable very bright point sources at these energies)
- Room for movement at ~10 keV and above (more so at higher energies) – Note there are presently CCF PSF entries at 8 keV, 10 keV and 13.25 keV (M1/M2/pn)
- Can get change of 20% in EE at 13.25 keV (up or down)
- SS’s results suggest a high-energy flattening of PSFs required (believed allowable within scatter of best PSF data points)
- Also FH’s high-energy pn residuals...
Related point 2 – Incorrect values calculated via extrapolations, interpolations, spline fittings etc.
- Large/sudden changes in parameters can lead to very large, unrealistic extrapolated values
- Analysis shows that spline fitting to points also has gross effects far from region of large changes (here, at very low-E)
- Hence, high-energy effective area values also subsequently effected
- Tiny changes to individual point values can lead to sensible/realistic spline fits
  - General warning that interpolations may not be giving what we expect
  - Also CAL interpolation may be different from e.g. this interpolation
XRT Point Spread Function

- Timing mode PSF
Radial Profile

Imaging mode:
Enclosed energy obtained by integrating surface brightness within circle
Timing mode:
Enclosed energy obtained by integrating surface brightness within thin strip extending to edge of detector
Timing mode PSF has been implemented in the development server for arfgen for MOS and pn (also pn burst mode)

SAS release expected end May/June (RDS)