The EPIC PSF : Into The SAS

Andy Read

Richard Saxton
Simon Rosen
Jose Ramirez
Georg Lamer
Carlos Gabriel
Matteo Guainazzi
From EllBeta+Gauss to the Full 2-D PSF

- Stacked images in general work well in emldetect
- Can model these Ellbeta+Gauss images
- Can create idealized images from these models (e.g. >)
- These however have a smeared azimuthal dependence (created from several sources at different azimuths)

Need to (in CAL/CCF/emldetect):
- choose/create the correct EB+G image (instrument, off-axis angle, energy)
- rotate the EB+G image for the detector position of the source
- filter in the known azimuthal (spokes etc.) dependence, i.e. filter the EB+G image azimuthally, retaining overall profile, and including correct angles, offsets, spoke sizes etc
- filter in (via similar method) any gross azimuthal filtering (e.g. the MOS2 ‘triangle’)

The star-like pattern – the ‘spokes’ – is created by the spider which supports the 58 co-axial Wolter I mirrors of the telescope.
Spokes modelled by a Flat-Topped Triangular Function

Profile needs to be such that no change is introduced to the full (360°) radial profile – i.e. areas need to cancel out

Estimated (from the data) widths of various components

\[ H = \frac{2}{2X + Y} - 1 \]
Strong effect! (45%)
3-peaked cosine function fits well
(peaks at 50°, 170°, 290°)
Point Spread Function: Six stages towards a full 2-D PSF

Full AMR 2-D PSF can be reproduced in the CAL
(from last meeting) Full 2-D PSF – Testing (to be done)

- AIP to incorporate into emldetect and perform testing – idea is to make ELLBETA PSF an option in emldetect, with the default still set to MEDIUM
- SSC to test emldetect with ELLBETA over many fields (all types – normal, crowded, problem fields) – compare results
- Continuing spectral tests (ESAC) of bright off-axis (and on-axis) sources with arfgen and ELLBETA
- Rigorous spectral analysis of bright sources using complex models and various extraction 'radii'
- (Future) Re-stacking, re-modelling of more data to obtain better EBG parameters – update CCFs – especially at high-energies...
New Ellbeta parameters

- Re-analysis, cleaning and stacking of more data
- New improved version (+syntax) of CIAO-sherpa
- Re-evaluation of energy bands (now 7, with 2 at high energy [7-9keV & 9-15 keV])
- Individual manual fitting for each data point (3 instr x 6 offax x 7 energy = 126)
- New parameters checked and input into CCFs (0010)
ELLBETA Parameters in CCF Files

core radius Ro, slope alpha, ellipticity, Gaussian FWHM, K-G norm.ratio
Progress and Problems

- Ingestion of AMR PSF code into CAL (king, gaussian, combine, spokes, secondary spokes, triangle/pentagon, r-dependent smooth)
- Ingestion of Ellbeta parameters into CCFs (latest: 0010) - problems with spline interpolations
- Detection runs produced many problems with: position angle, phi, spoke positions, triangle positions, source orientations... (plus ‘accuracy’-dependent differences)
- Very complicated (many coordinate systems & transforms) and badly documented (if at all) - Many exchanges & development iterations necessary
- Problems only noticeable as we now have a complex (and non-symmetric) PSF system
- Likely that the system up to now has been incorrect, though not noticeable
Spline Problems:

- Tiny changes in parameter values of the fiducial calibration points can result in very large changes in the interpolated values.
- Seen in PSF parameters ('04 and '09/'10) - may be visible in other CCF parameters
- Experimented with ‘Closest Point’ (CP) and ‘Linear Interpolation’ (LI - ‘dot-to-dot’) approaches
- LI approach looks fine and this is being used for the PSF parameter interpolation (RDS)

CAL spline fits to PSF parameters
(slides: AMR CAL meet March 2004)
RDS : Radial profiles from many individual point sources fitted with Ellbeta models
All instruments, low and high energies
On-axis
RDS : Radial profiles from many individual point sources fitted with Ellbeta models
All instruments, low and high energies
Off-axis
...and at the very highest energies (band5: 4.5-12 keV) and largest off-axis angles

- 6kev calibration points used in this band5 fitting
- Aim is for the source-searching to use the 6keV points when source-searching in band5 (the 6keV energy points are better calibrated and are where most of the band5 photons are)
JR: Inclusion of latest Ellbeta PSF and CAL into detect chain
Detect chain ran on many fields
JR: Inclusion of latest Ellbeta PSF and CAL into detect chain
Detect chain ran on many fields
Boundary problems with current default medium PSF (images) mitigated with Ellbeta PSF (analytic functions)
Spurious Sources?

JR: Comparison of sources detected using the current default medium PSF (yellow) with sources detected using the Ellbeta PSF (blue) over several fields. Generally there are fewer detections close to bright sources using Ellbeta than using medium.
Spurious Sources?

- Numbers of sources detected as a function of distance from the central bright source using the Ellbeta PSF (red) and the medium PSF (black) for 16 individual cases
- Fewer detections around bright sources when the Ellbeta PSF is used
SR:
- SSC (Leics) detection chains on several (56) datasets using Ellbeta and medium PSFs
- Source and model counts within 32 azimuthal (on-spoke/off-spoke) and 30 radial bins
- PA used to ensure azimuthal bins correspond to same azimuth on the PSF
- Values stacked for ~80 bright target sources - statistics evaluated

data
model
chi2 = +/- (data-model)^2/model
r = sum(chi2/|chi2|)
PN 0.5-1keV 0-2 arcminutes

Dark stripes: CCD boundaries * OOTs * Medium model deficit at 1acrm, and large discrepancies at spokes * Ellbeta great improvement - perhaps overspoking (at least at small r)
Source maps for MOS1, MOS2 and pn - Note that the pn OOTs (6.7%) are modelled, whereas the MOS OOTs (0.5%) are not
MOS2 0.5-1keV 0-2 arcminutes
Medium model deficit at 1arcmin, and large discrepancies at spokes and M2 triangle * 3 o’clock feature? - No OOTs * Ellbeta great improvement - triangle effect perhaps too intense
MOS1 0.5-1keV 0-2 arcminutes
Medium model deficit at 1 arcmin and large discrepancies at spokes * pentagon visible in medium residuals  * Ellbeta great improvement - pentagon effect perhaps not strong enough
MOS2 0.5-1keV 9-15 arcminutes
Medium model triangular discrepancy very visible and smaller discrepancies at spokes
SR:
• SSC (Leics) detection chains on several (56) datasets using Ellbeta and medium PSFs
• Compare detection likelihoods and count rates for sources detected with both the Ellbeta PSF and the medium PSF - 4830 sources and 77 bright sources
• Histograms of fractional change (ellbeta-medium)/medium

• Likelihood difference clustered tightly around zero - not yet obvious why
• Likelihood difference for bright sources also ~zero
Count rate differences show a slightly higher count rate using Ellbeta, around 2%
PN Pentagon

Constant offset between actual telescope boresight and bright target aimpoint for most of the 'on-axis' sources (i.e. most of the ‘on-axis’ sources are at the same phi) has preserved much of the mirror structure (spokes partly survive) and pentagonal structure is seen.

(pn 0.0-1.5arcmin 1-2 keV)
PN Pentagon

Angles ~45, 117, 189, 261, 333

Add 90 (MOS1 to pn), then get the MOS1 pentagon angles...?
Arfgen

A consequence of the Ellbeta PSF is that arfgen can now work with images rather than with analytic functions.

This may allow in the future a user to work with the best spectrum possible, with complicated shapes describing (inner) the removal of pile-up (to a constant level) and (outer) maximizing the signal-to-noise. Also better handling of bad (dark) columns.

Note MOS OOTs
The Full 2-D PSF – Futures near and far...

• Under- and over-spoking (+ gross azimuthal filtering) re-calibration
• More clean data needed for better PSF parameterization, especially at high energies and large off-axis angle
• More testing, especially spectrally and with varying extraction annuli etc.
• More testing of detect chain output - likelihoods, rates, fluxes, extents, spurious sources, sources close to bright sources etc.
• Proper handling of the Sagittal-Meridional effect (off-axis and energy dependent) - not yet included
• MOS events spread across the RGS dispersion axis – Is this a PSF issue?
• Out-of-time events - Is this a PSF/emldetect issue? MOS/pn?
• Azimuthal phi-dependence of the Ellbeta parameters, e.g. RGA obscuration, individual chip-to-chip height variations (MOS)
• Pentagon in pn - requires calibration and azimuthal filtering
• Dark lanes due to electron deflector - not yet included
• ...
End