XRT Point Spread Function

- Shifts in PSF position with energy
- King + Gaussian profile fitting

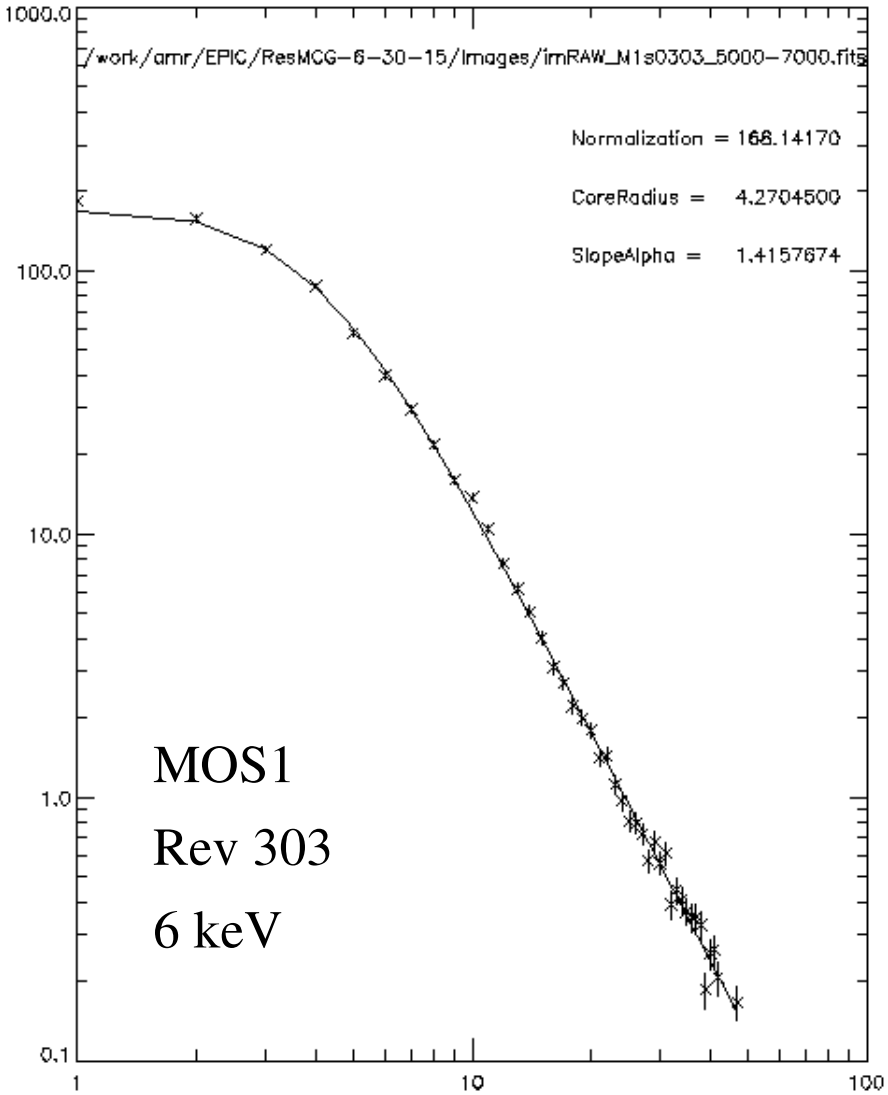
- Off-Axis PSF

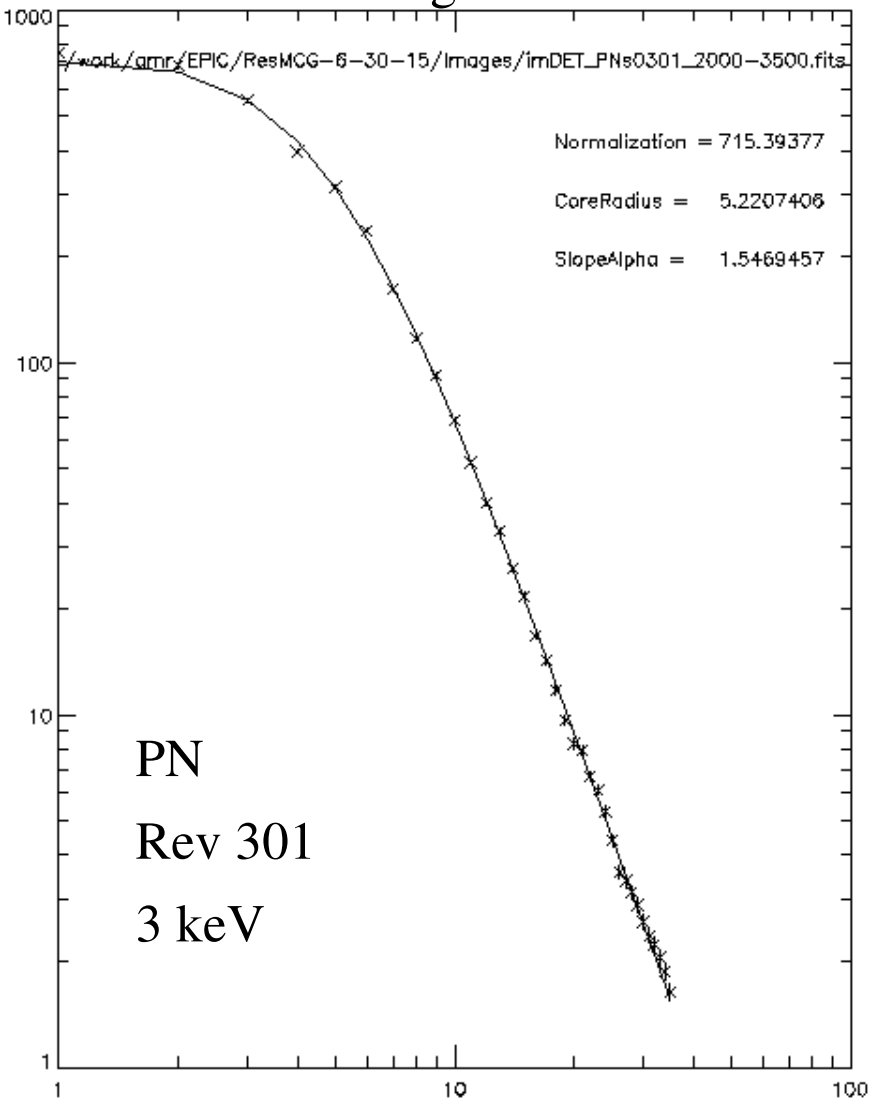
- Timing mode PSF

Andy Read (amr30@star.le.ac.uk)

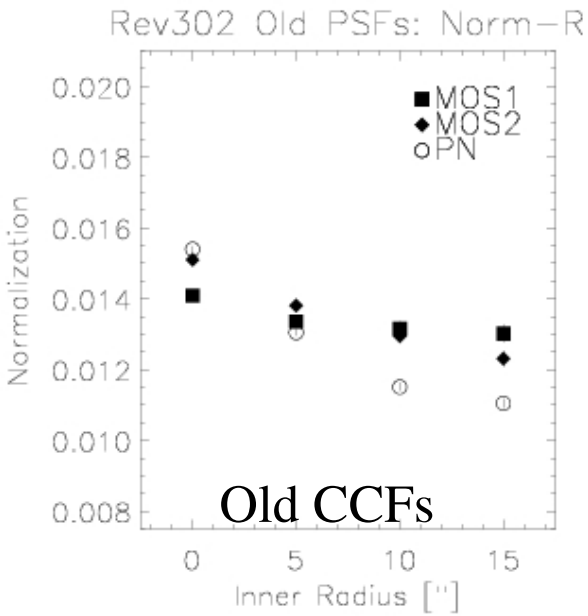
MCG-6-30-15

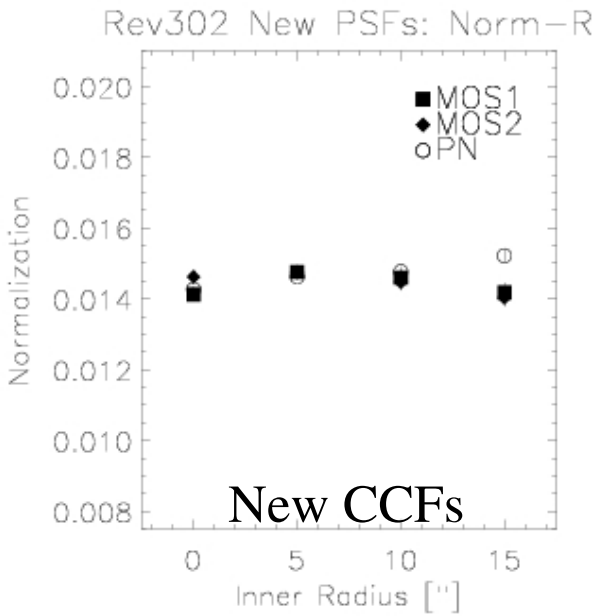
Examples of King profile fits to narrow-band images

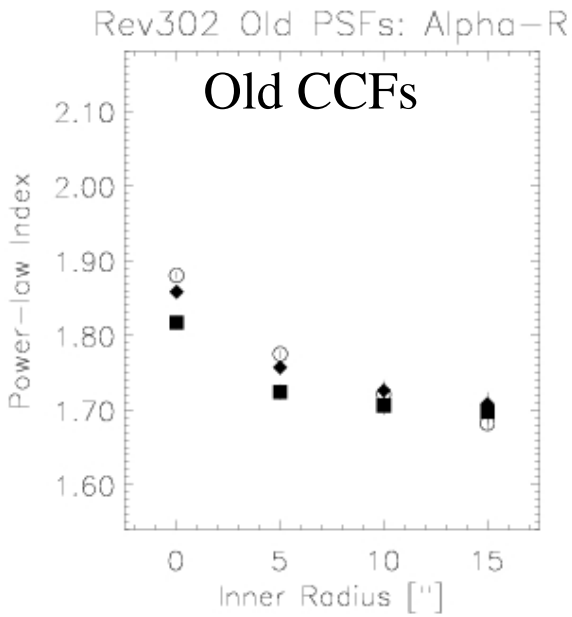


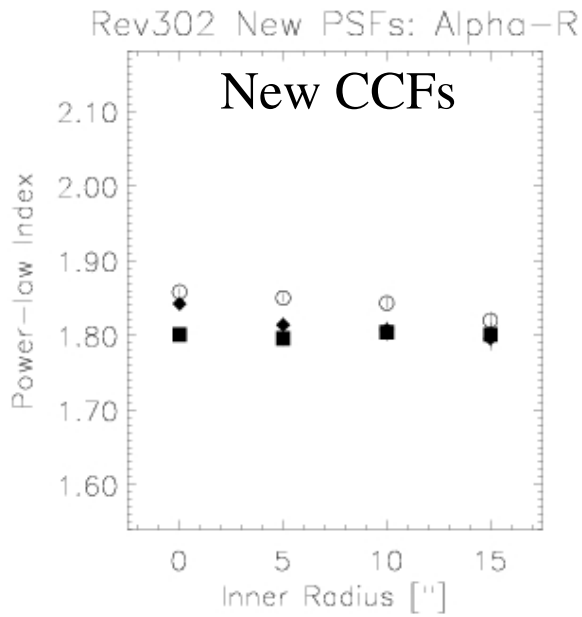


MCG-6-30-15









- New XRT PSF CCFs yield consistent spectral parameters as a function of extraction radius

XRT Point Spread Function

- Shifts in PSF position with energy

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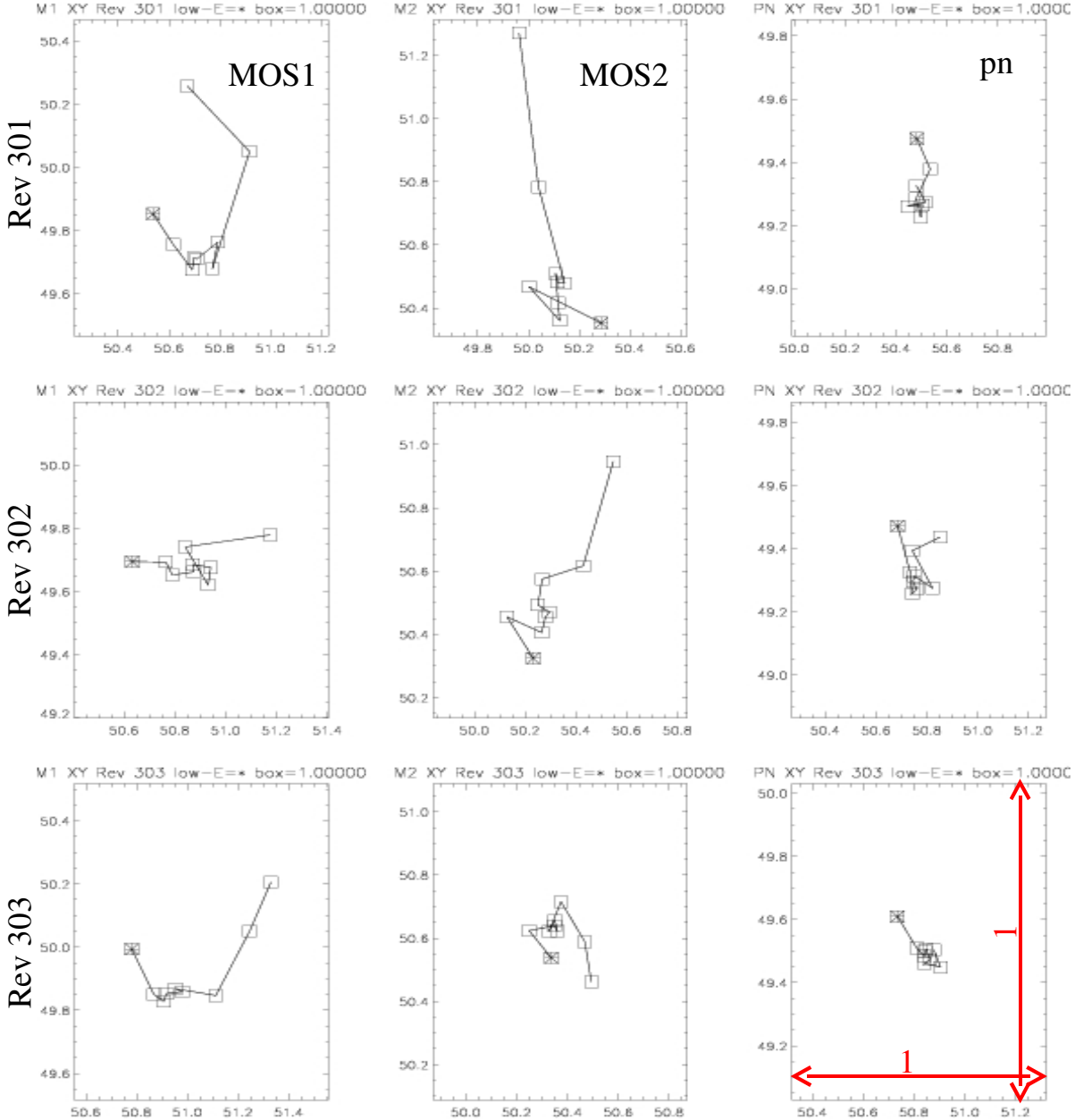


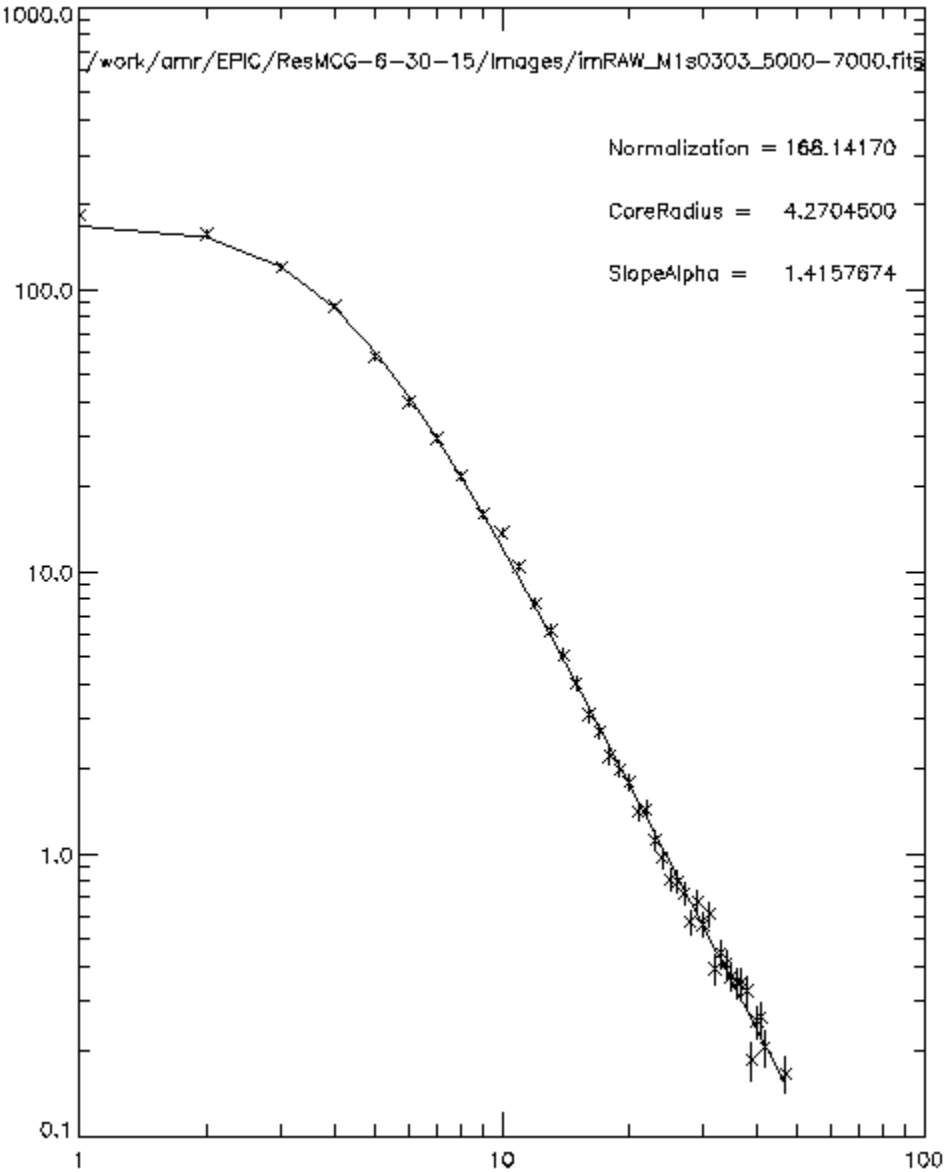
- Lines show shift in PSF centroid position with increasing energy (✱ = lowest energy)
- Shifts are small << 1 arcsec in most cases
- Stats not very good at highest energies (some larger shifts suggested)

XRT Point Spread Function

- King + Gaussian profile fitting

Andy Read (amr30@star.le.ac.uk)

PSF King+Gaussian [KG] Fitting

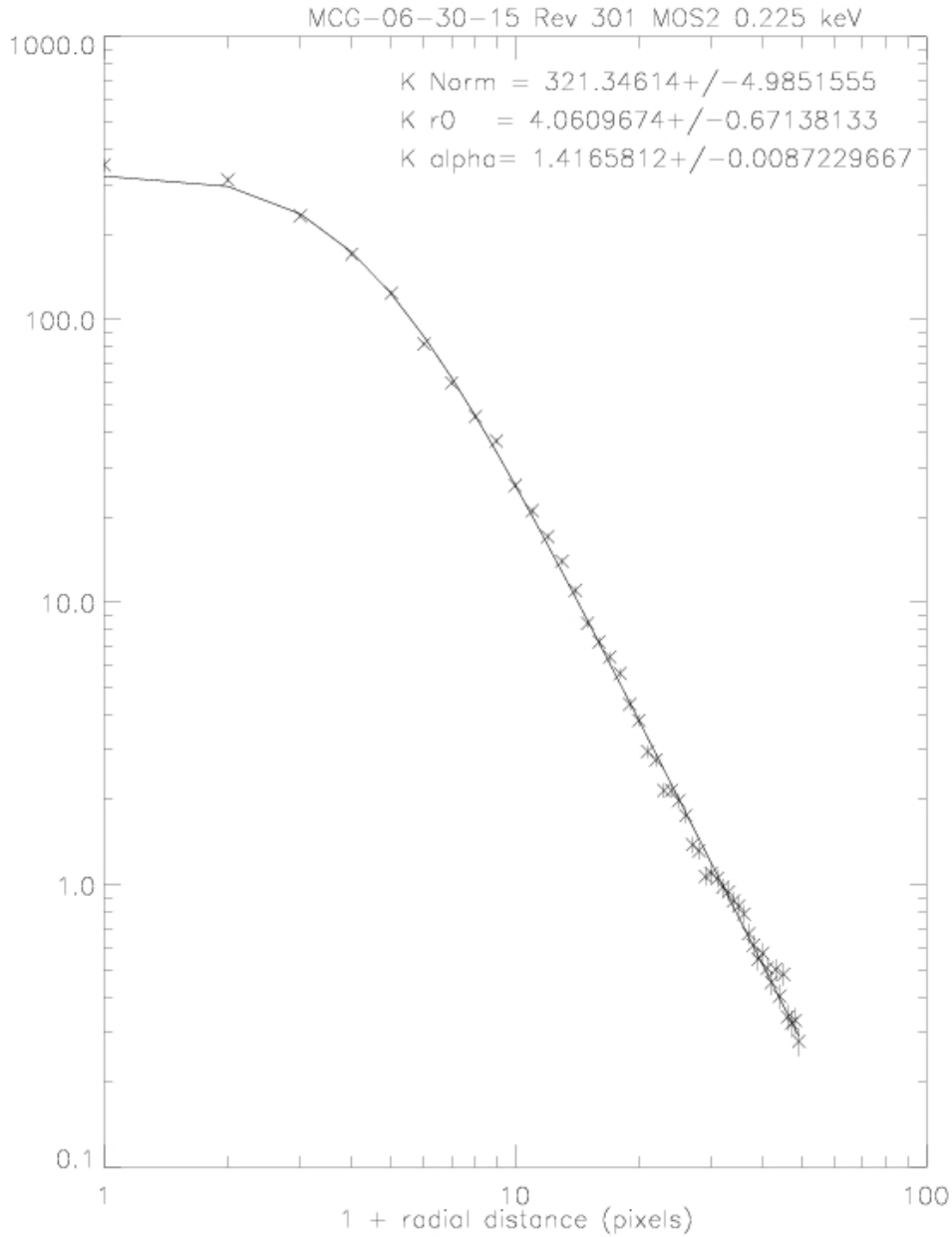


- King fits sometimes underestimate the PSF profile at the very centre

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

↑ KING + ↑ GAUSSIAN

- Would require new software [CAL, arfgen etc…]

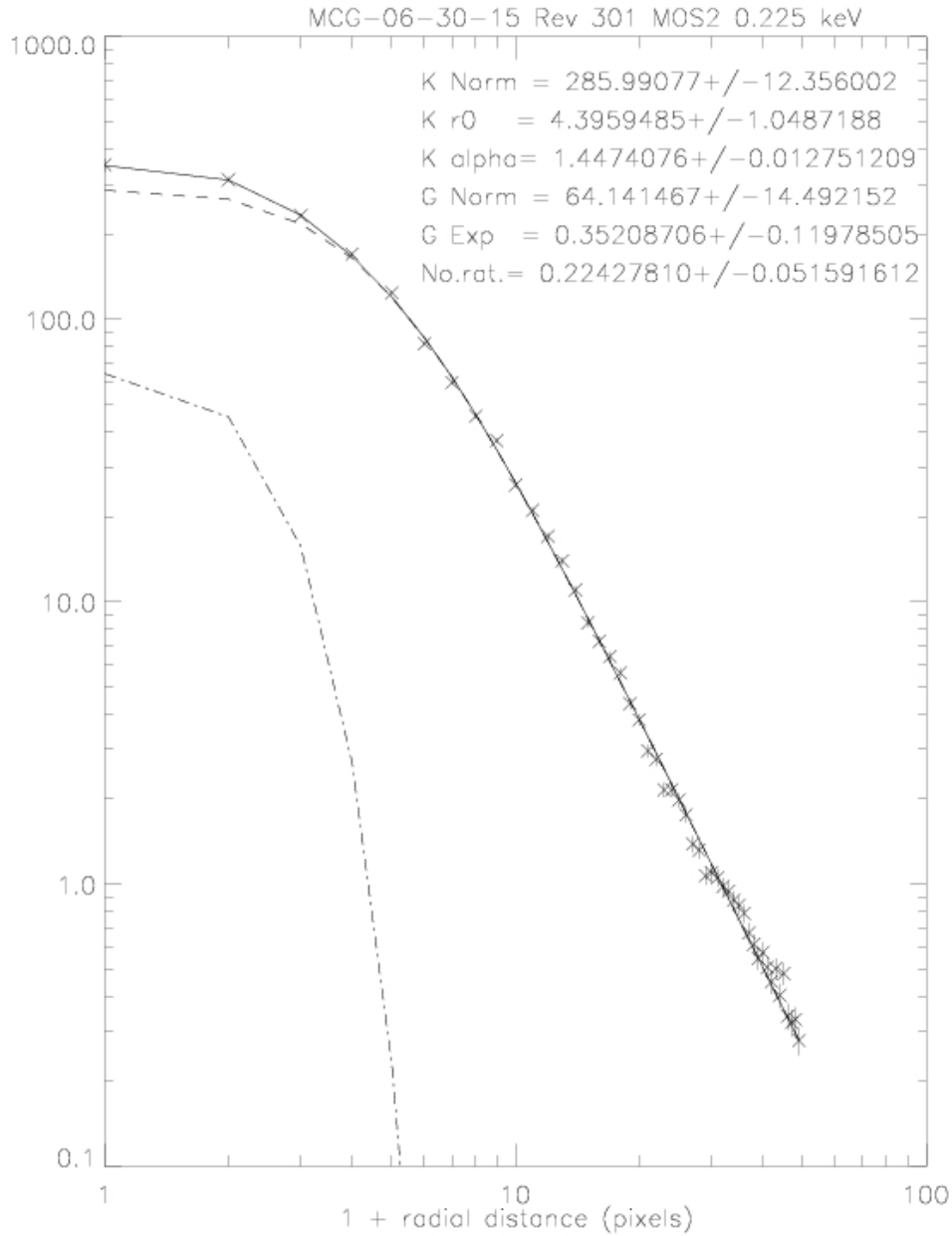


Example :

MOS2 - Rev 301 (MCG-06-30-15)

0.225 keV

King fit



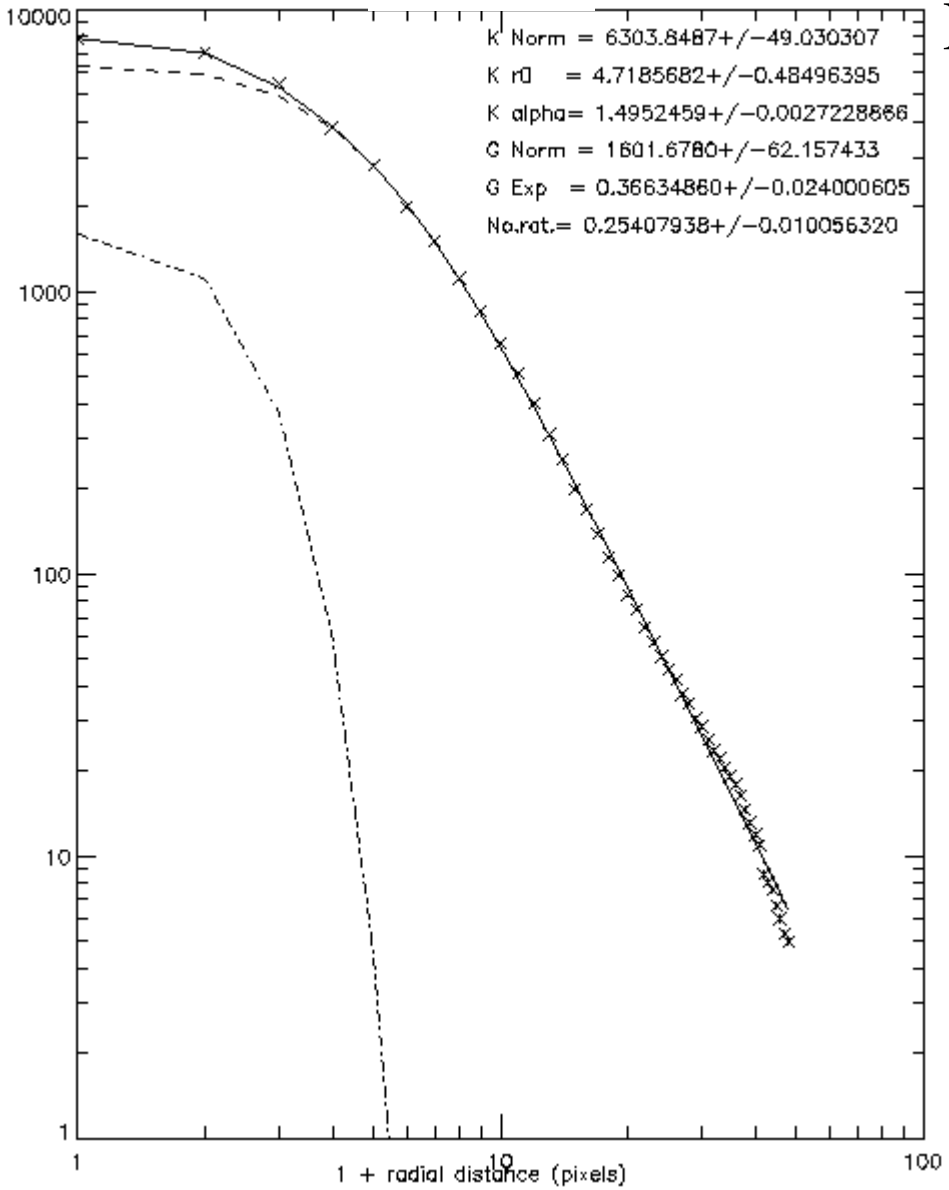
Example :

MOS2 - Rev 301 (MCG-06-30-15)

0.225 keV

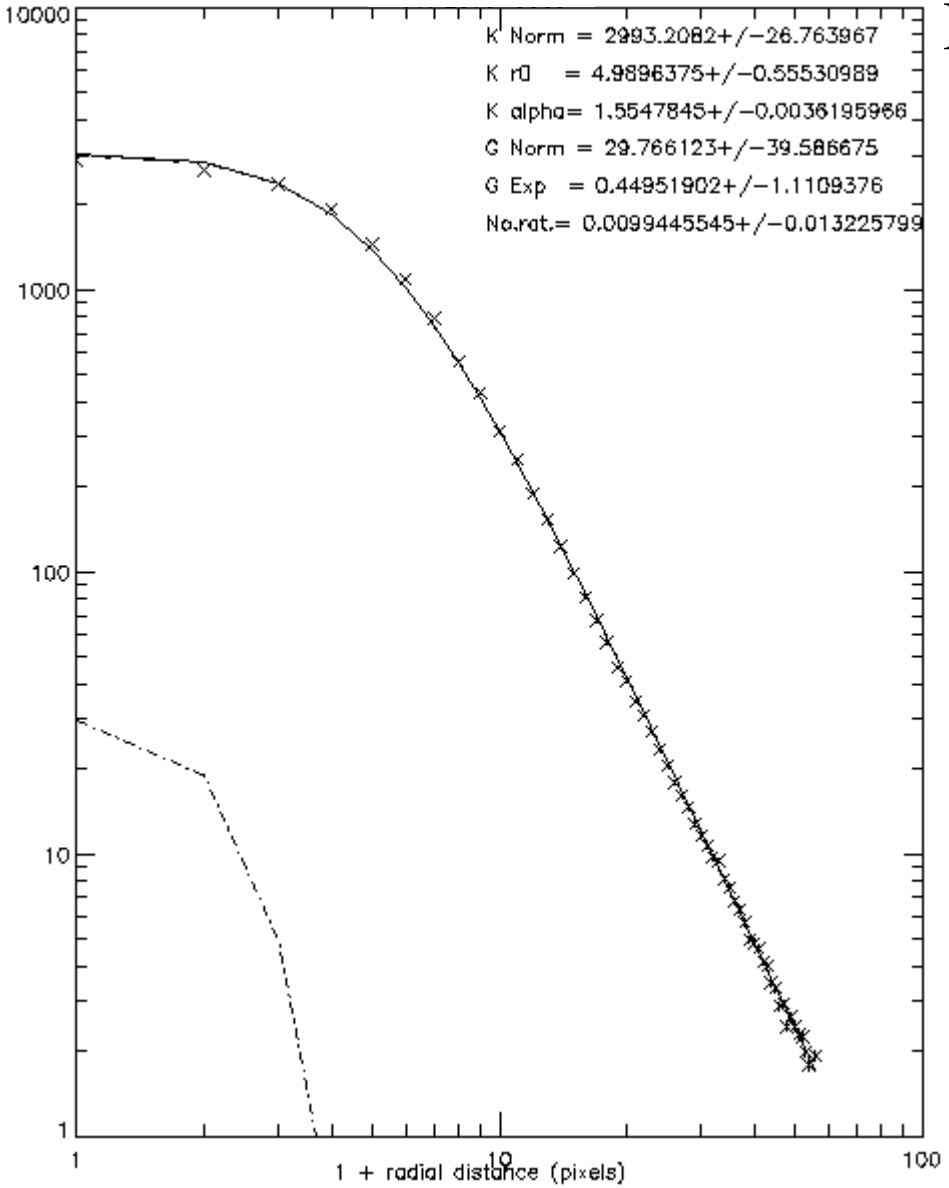
King + Gaussian fit

PSF King+Gaussian [KG] Fitting

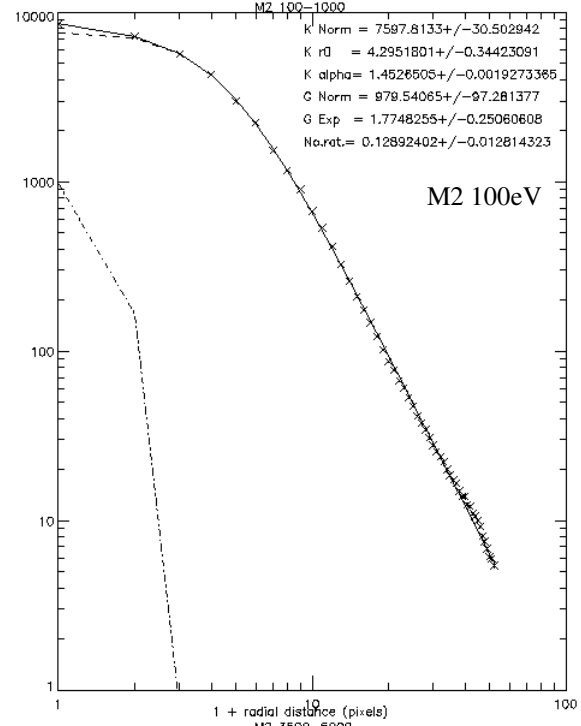


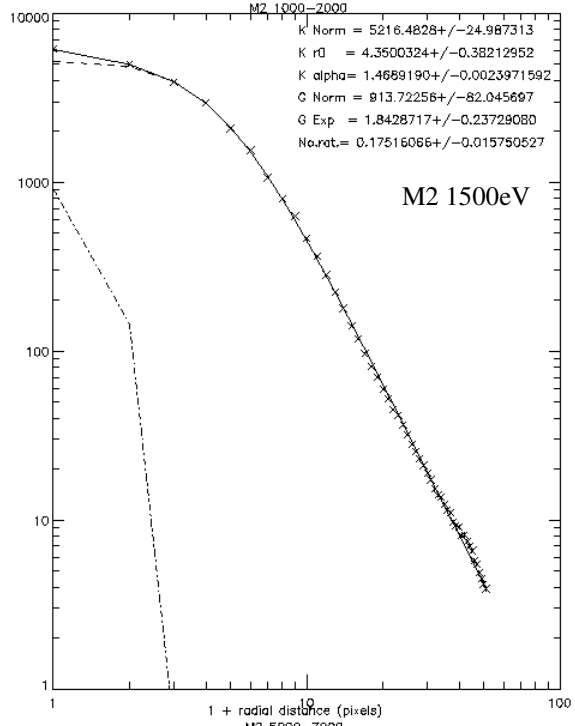
- e.g. M1 100 eV
- Substantial Gaussian component allowed (ratio of normalizations 25±1%)

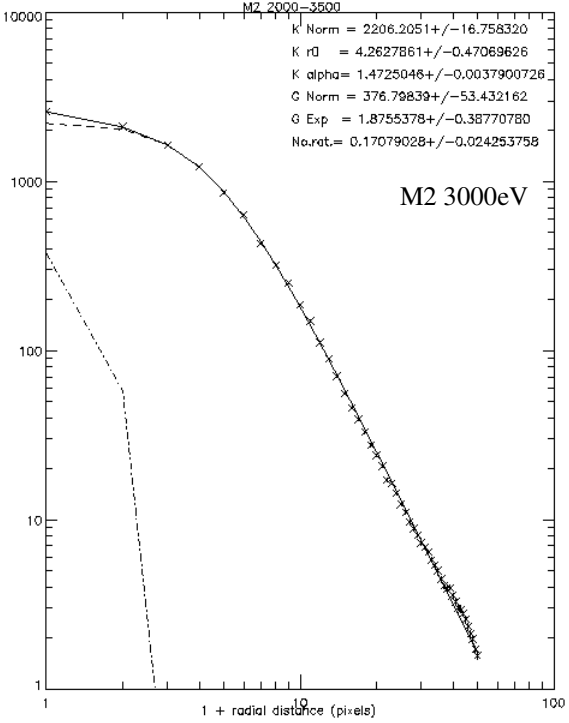
PSF King+Gaussian [KG] Fitting

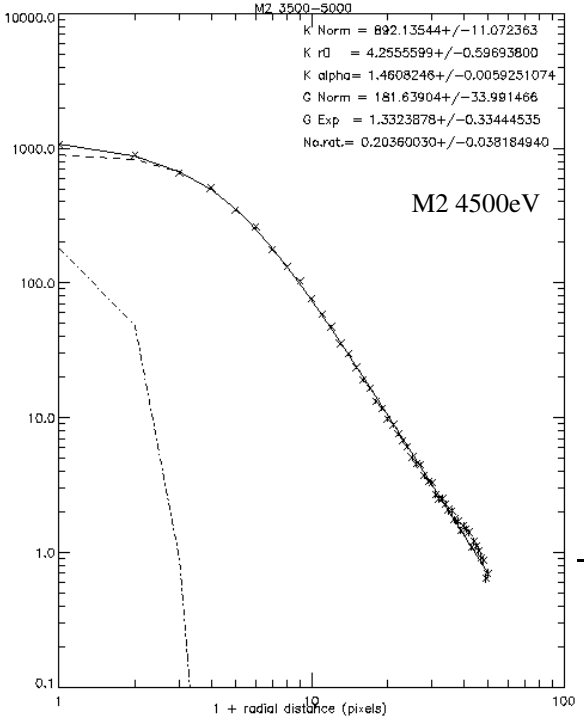


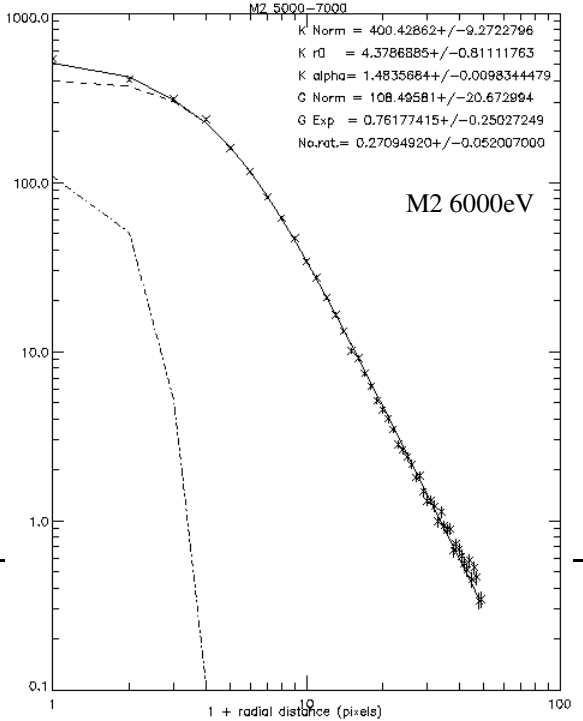
- e.g. PN 3000 eV
- Very small (~0) Gaussian component required (ratio of normalizations 1±1%)
- PN's larger pixels insensitive to the very core of the PSF

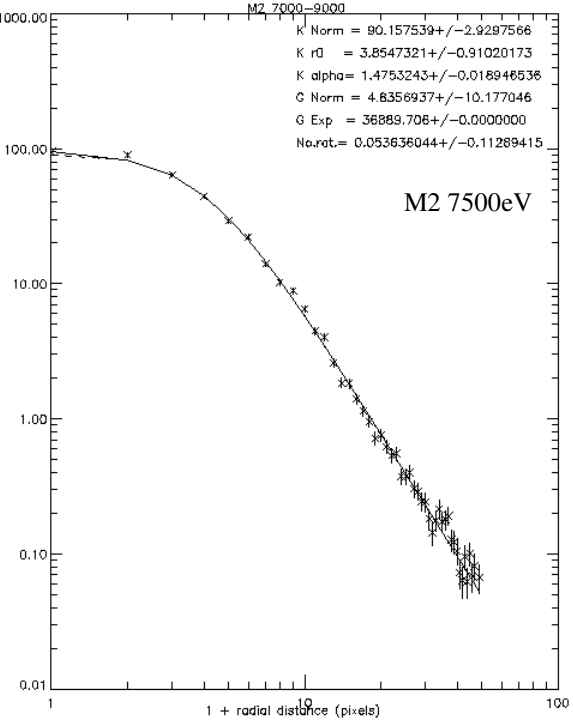

M2 100-1000
K Norm = 7597.8133+/-30.502942
K r0 = 4.2951801+/-0.34423091
K alpha= 1.4526505+/-0.0019273365
G Norm = 979.54065+/-97.281377
G Exp = 1.7748255+/-0.25060608
No.rat.= 0.12892402+/-0.012814323
M2 100eV
1 + radial distance (pixels)


M2 1000-2000
K Norm = 5216.4828+/-24.987313
K r0 = 4.3500324+/-0.38212952
K alpha= 1.4689190+/-0.0023971592
G Norm = 913.72256+/-82.045697
G Exp = 1.8428717+/-0.23729080
No.rat.= 0.17516066+/-0.015750527
M2 1500eV
1 + radial distance (pixels)

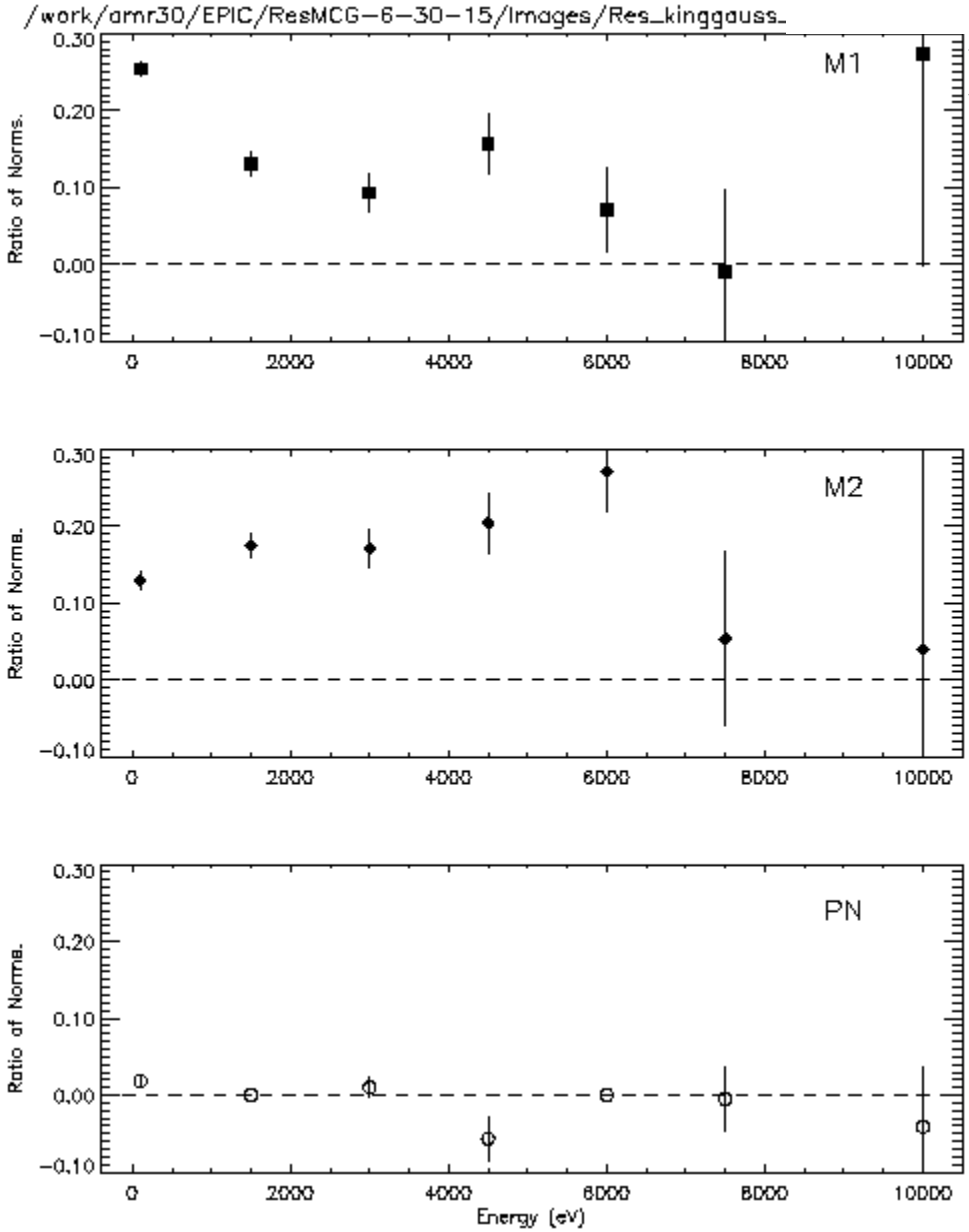

M2 2000-3500
K Norm = 2206.2051+/-16.758320
K r0 = 4.2627861+/-0.47069626
K alpha= 1.4725046+/-0.0037900726
G Norm = 376.79839+/-53.432162
G Exp = 1.8755378+/-0.38770780
No.rat.= 0.17079028+/-0.024253758
M2 3000eV
1 + radial distance (pixels)


M2 3500-5000
K Norm = 892.13544+/-11.072363
K r0 = 4.2555599+/-0.59693800
K alpha= 1.4608246+/-0.0059251074
G Norm = 181.63904+/-33.991466
G Exp = 1.3323878+/-0.33444535
No.rat.= 0.20360030+/-0.038184940
M2 4500eV
1 + radial distance (pixels)

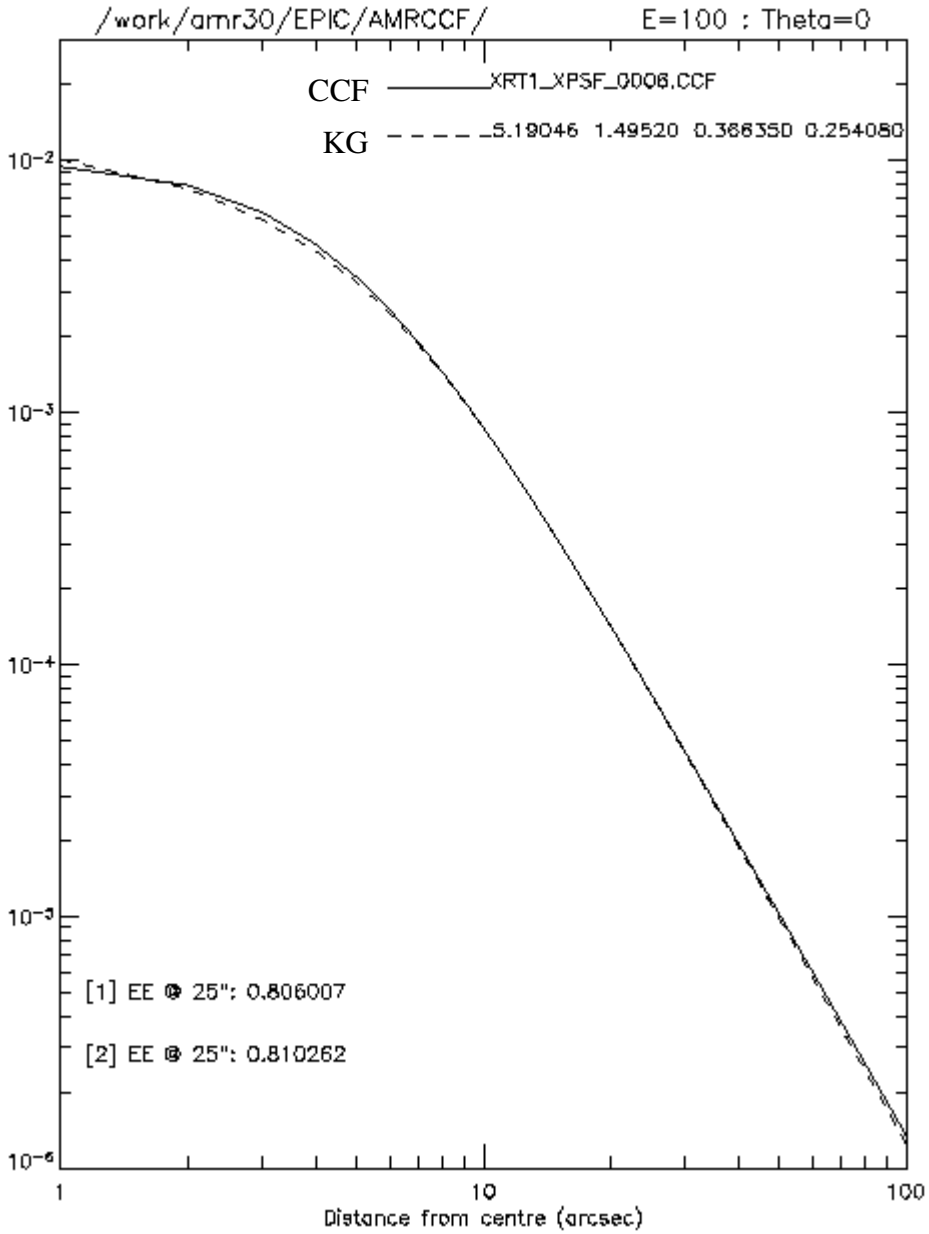

M2 5000-7000
K Norm = 400.42862+/-9.2722796
K r0 = 4.3786885+/-0.81111763
K alpha= 1.4835684+/-0.0098344479
G Norm = 108.49581+/-20.672994
G Exp = 0.76177415+/-0.25027249
No.rat.= 0.27094920+/-0.052007000
M2 6000eV
1 + radial distance (pixels)


M2 7000-9000
K Norm = 90.157539+/-2.9297566
K r0 = 3.8547321+/-0.91020173
K alpha= 1.4753243+/-0.018946536
G Norm = 4.8356937+/-10.177046
G Exp = 36889.706+/-0.0000000
No.rat.= 0.053636044+/-0.11289415
M2 7500eV
1 + radial distance (pixels)

PSF King+Gaussian [KG] Fitting



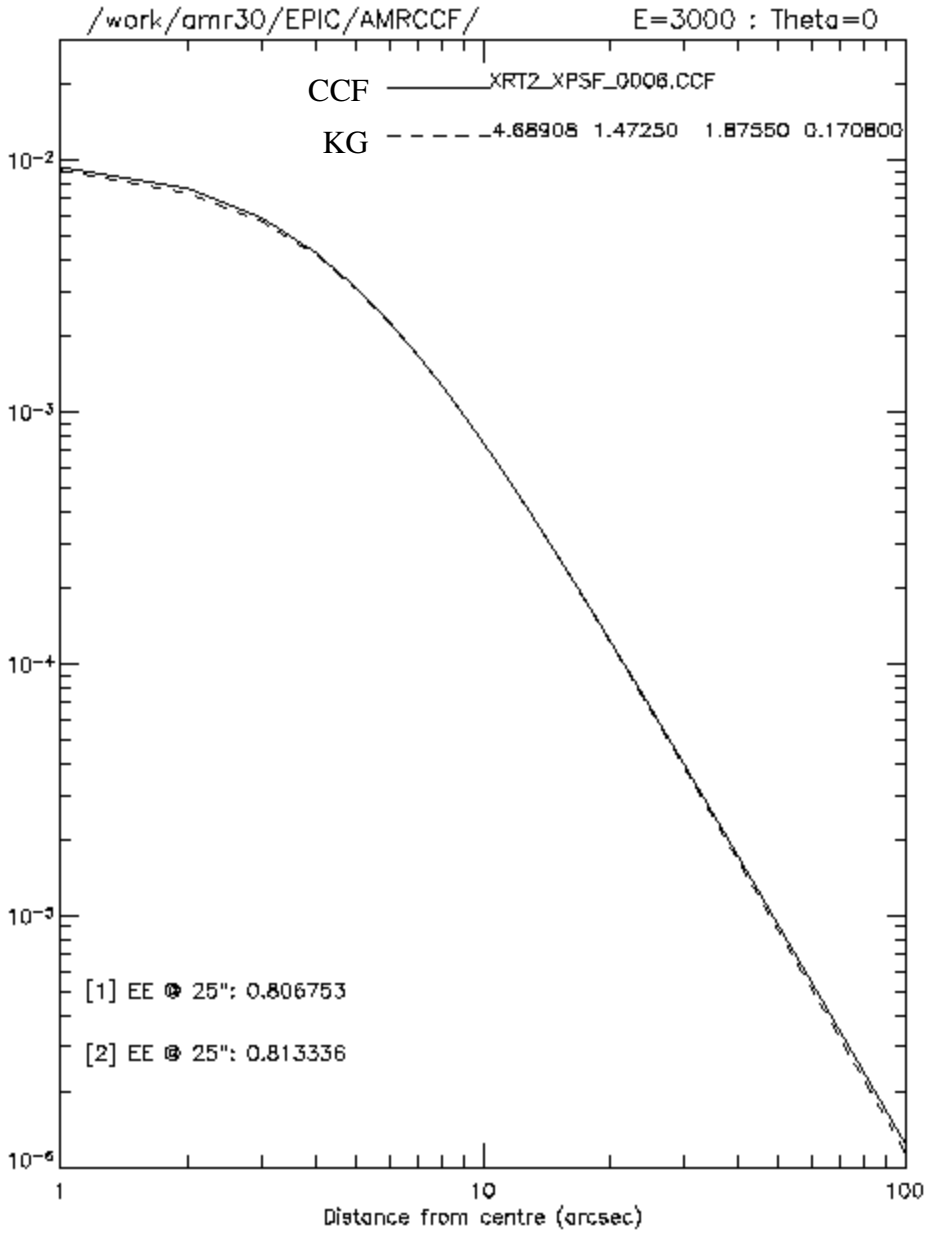
- Ratio of normalizations [Gauss/King] versus Energy
- M1/M2 : Significant Gauss component allowed, especially at low/medium-E – [no Gauss component required at high-E]
- PN : No Gauss component required (except perhaps at lowest-E [1.8±0.6%])



PSF King+Gaussian [KG] Fitting

- Comparison of present CCF PSF and KG PSF

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

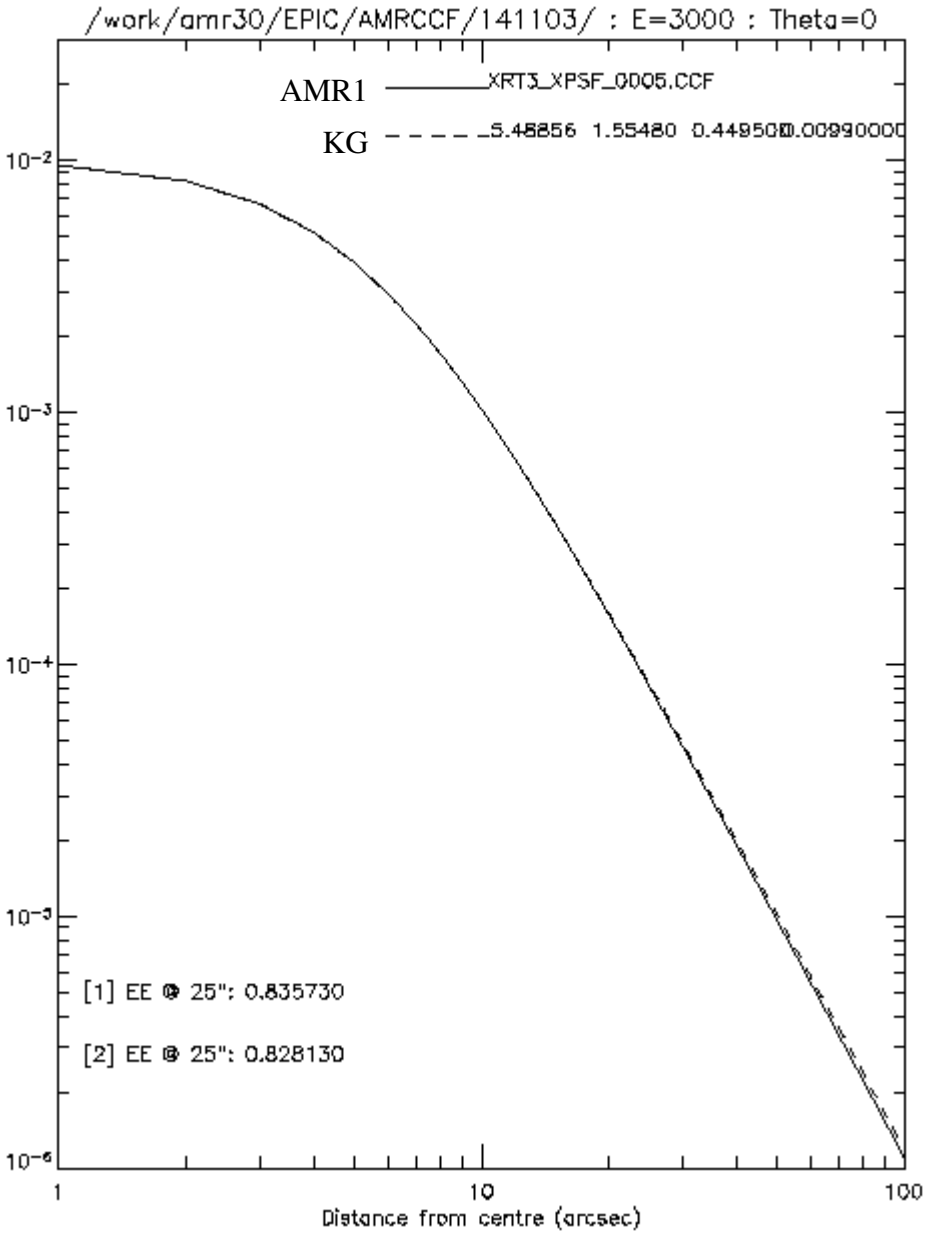


PSF King+Gaussian [KG] Fitting

- 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)



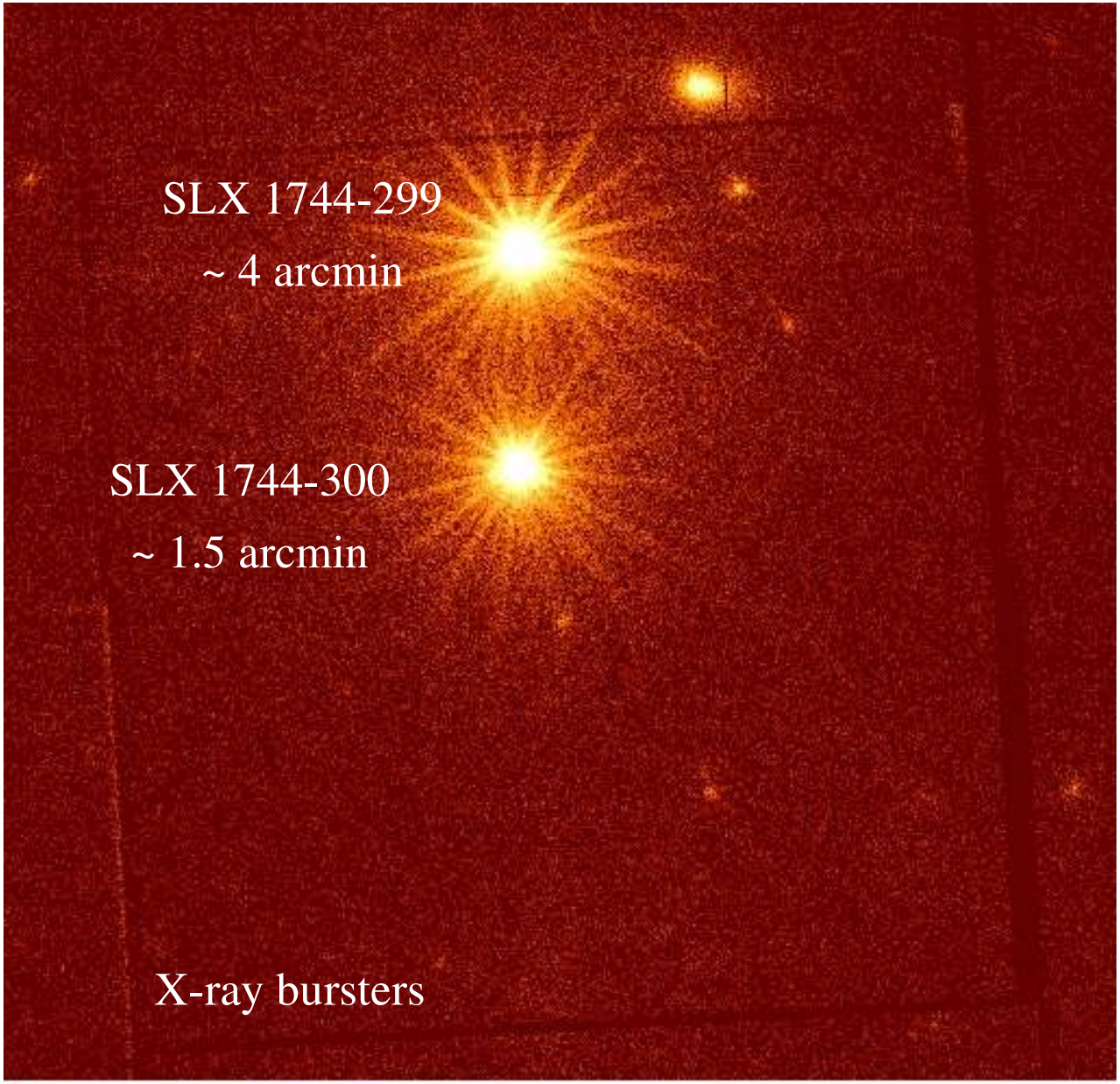
PSF King+Gaussian [KG] Fitting

- 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

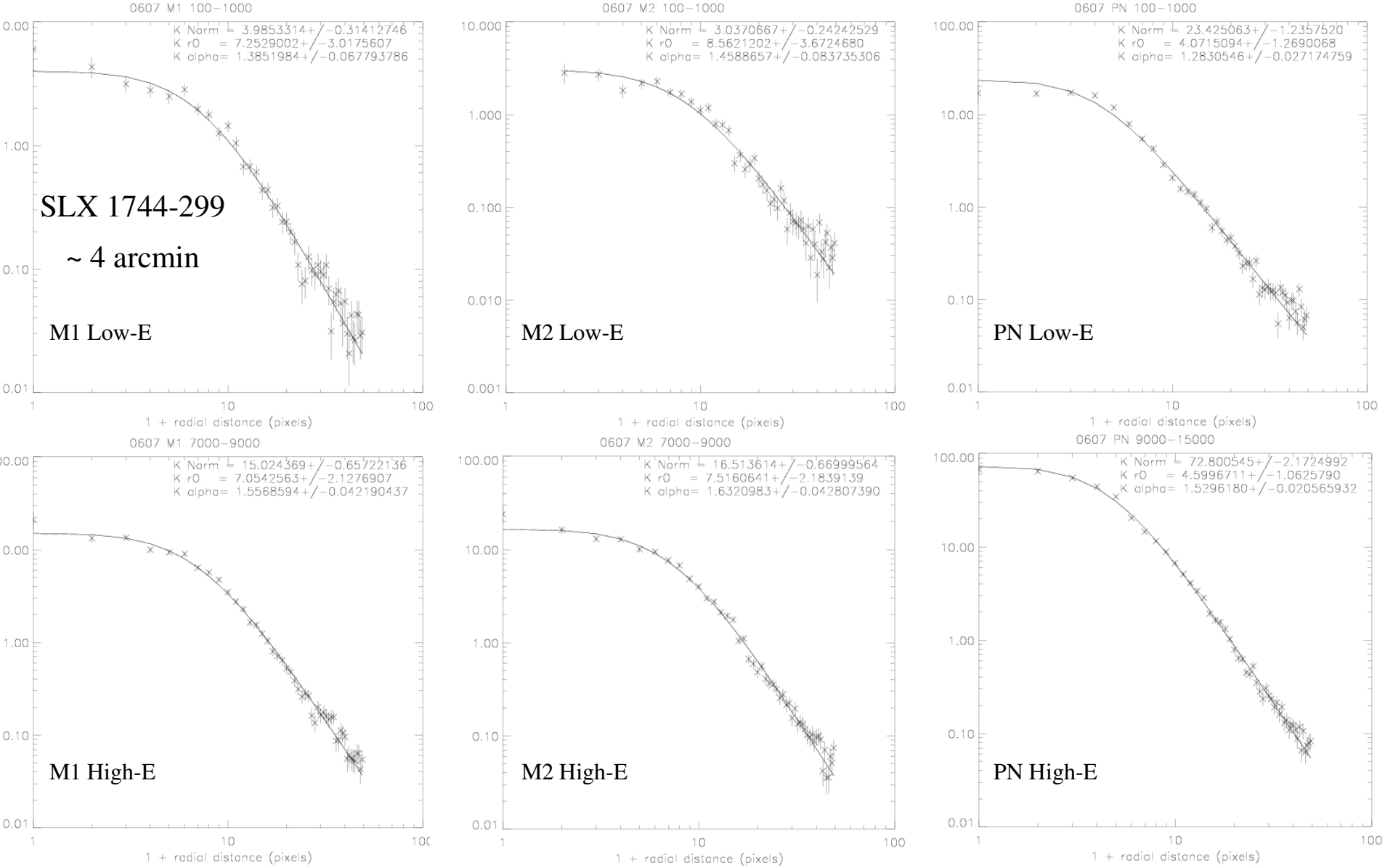
- Off-Axis PSF

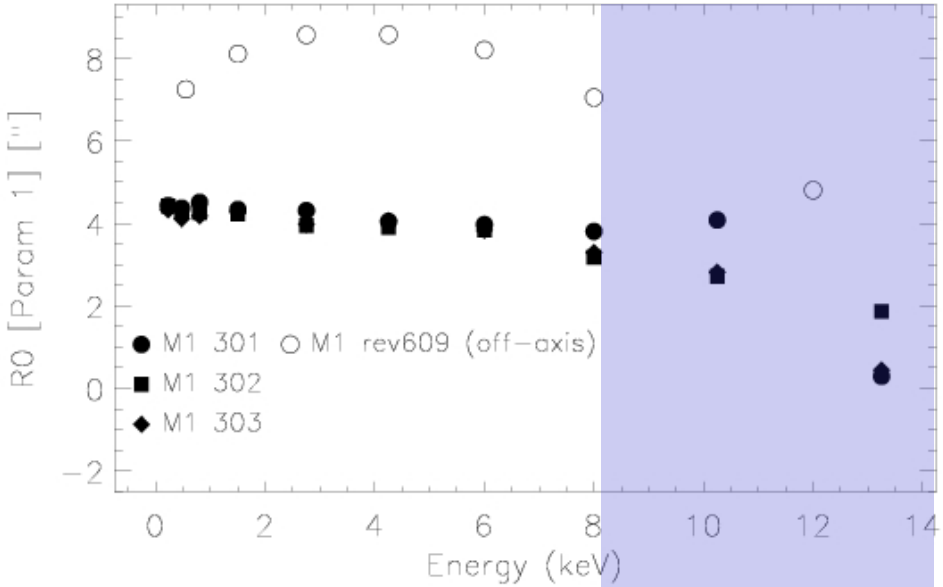
Andy Read (amr30@star.le.ac.uk)



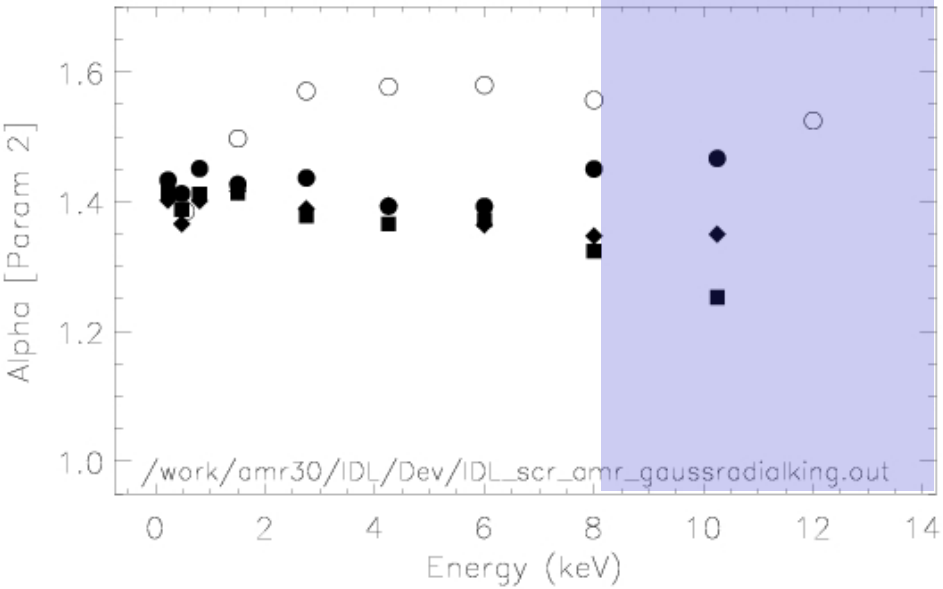
A few suitable off-axis sources are now appearing in the XMM archive

Andy Read (amr30@star.le.ac.uk)


0607 M1 100−1000
K Norm = 3.9853314+/−0.31412746
K r0 = 7.2529002+/−3.0175607
K alpha= 1.3851984+/−0.067793786
SLX 1744-299
~ 4 arcmin
M1 Low-E
0607 M2 100−1000
K Norm = 3.0370667+/−0.24242529
K r0 = 8.5621202+/−3.6724680
K alpha= 1.4588657+/−0.083735306
M2 Low-E
0607 PN 100−1000
K Norm = 23.425063+/−1.2357520
K r0 = 4.0715094+/−1.2690068
K alpha= 1.2830546+/−0.027174759
PN Low-E
0607 M1 7000−9000
K Norm = 15.024369+/−0.65722136
K r0 = 7.0542563+/−2.1276907
K alpha= 1.5568594+/−0.042190437
M1 High-E
0607 M2 7000−9000
K Norm = 16.513614+/−0.66999564
K r0 = 7.5160641+/−2.1839139
K alpha= 1.6320983+/−0.042807390
M2 High-E
0607 PN 9000−15000
K Norm = 72.800545+/−2.1724992
K r0 = 4.5996711+/−1.0625790
K alpha= 1.5296180+/−0.020565932
PN High-E
1 + radial distance (pixels)

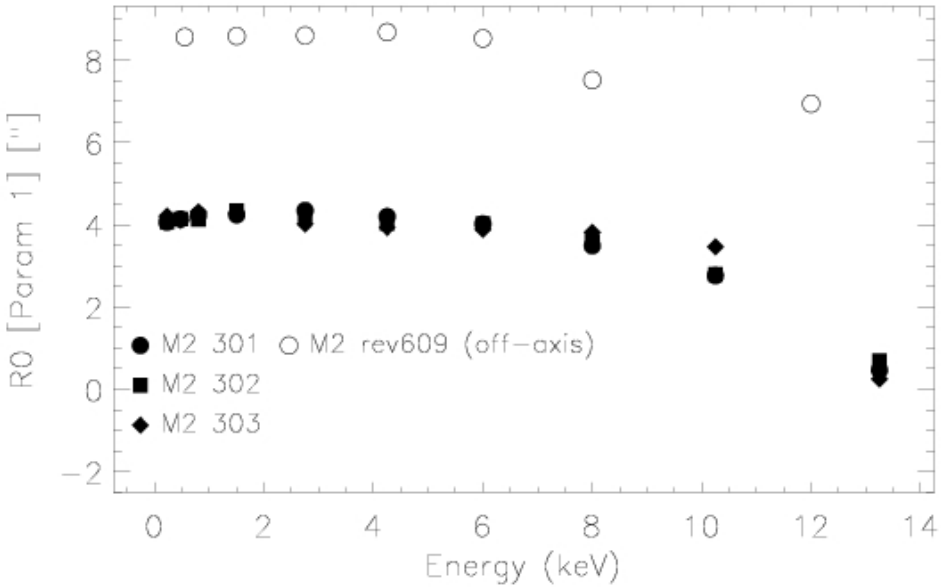


MOS1

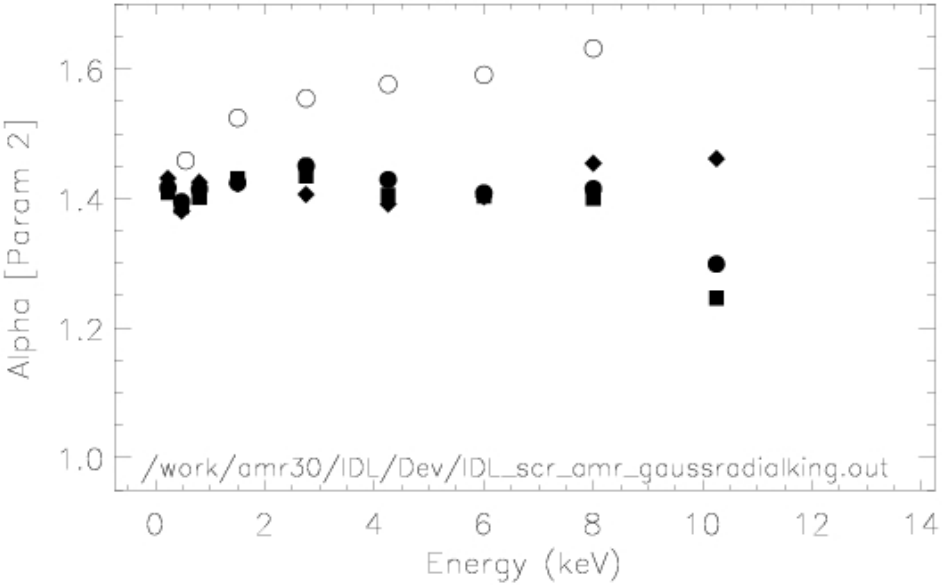


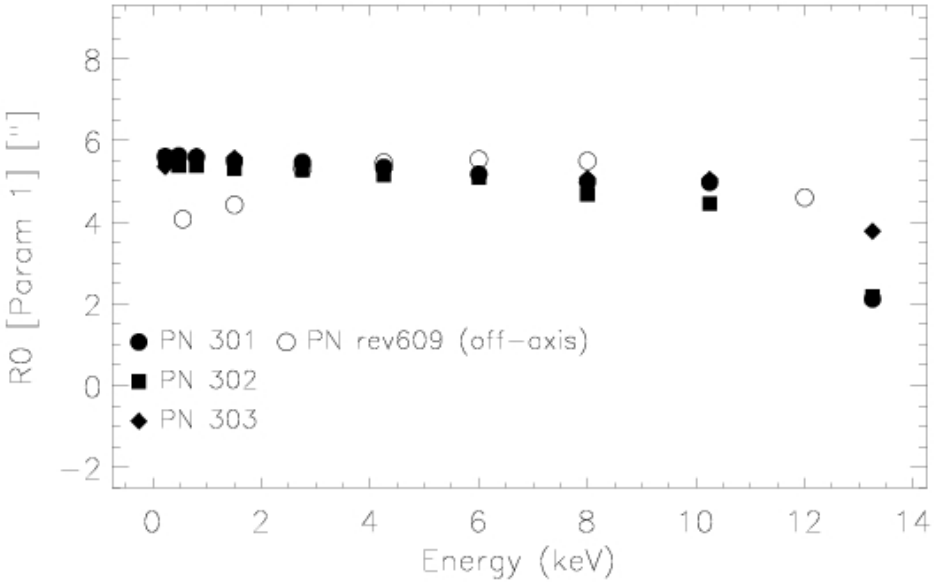
- Variations of R0 (King core radius) and (King slope) with energy
- Different behaviour from e.g. MCG-06-30-15 (on-axis, black points – used for CCF)

Note: PSF parameters used (partly) to determine the PSF show some scatter at high-energy

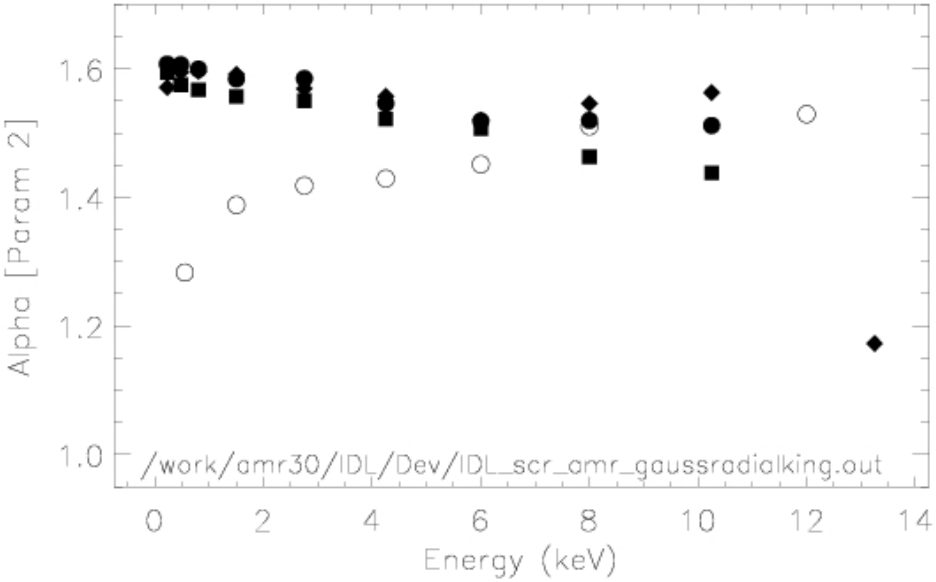

R0 [Param 1] ['']
Energy (keV)
M2 301
M2 rev609 (off-axis)
M2 302
M2 303

MOS2


Alpha [Param 2]
Energy (keV)
/work/amr30/IDL/Dev/IDL_scr_amr_gaussradialking.out

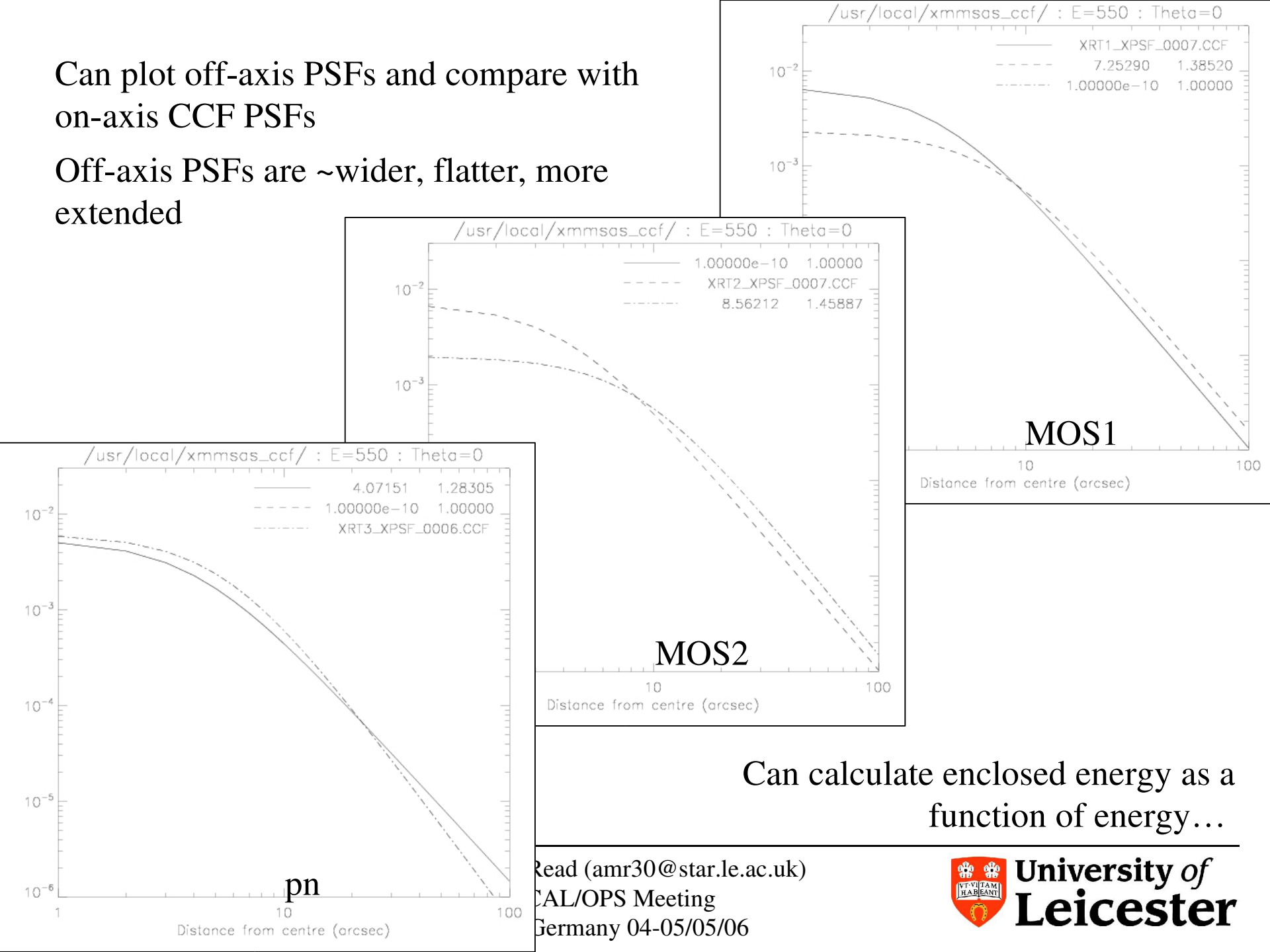

R0 [Param 1] ["]
Energy (keV)
PN 301
PN rev609 (off-axis)
PN 302
PN 303

pn


Alpha [Param 2]
Energy (keV)
/work/amr30/IDL/Dev/IDL_scr_amr_gaussradialking.out

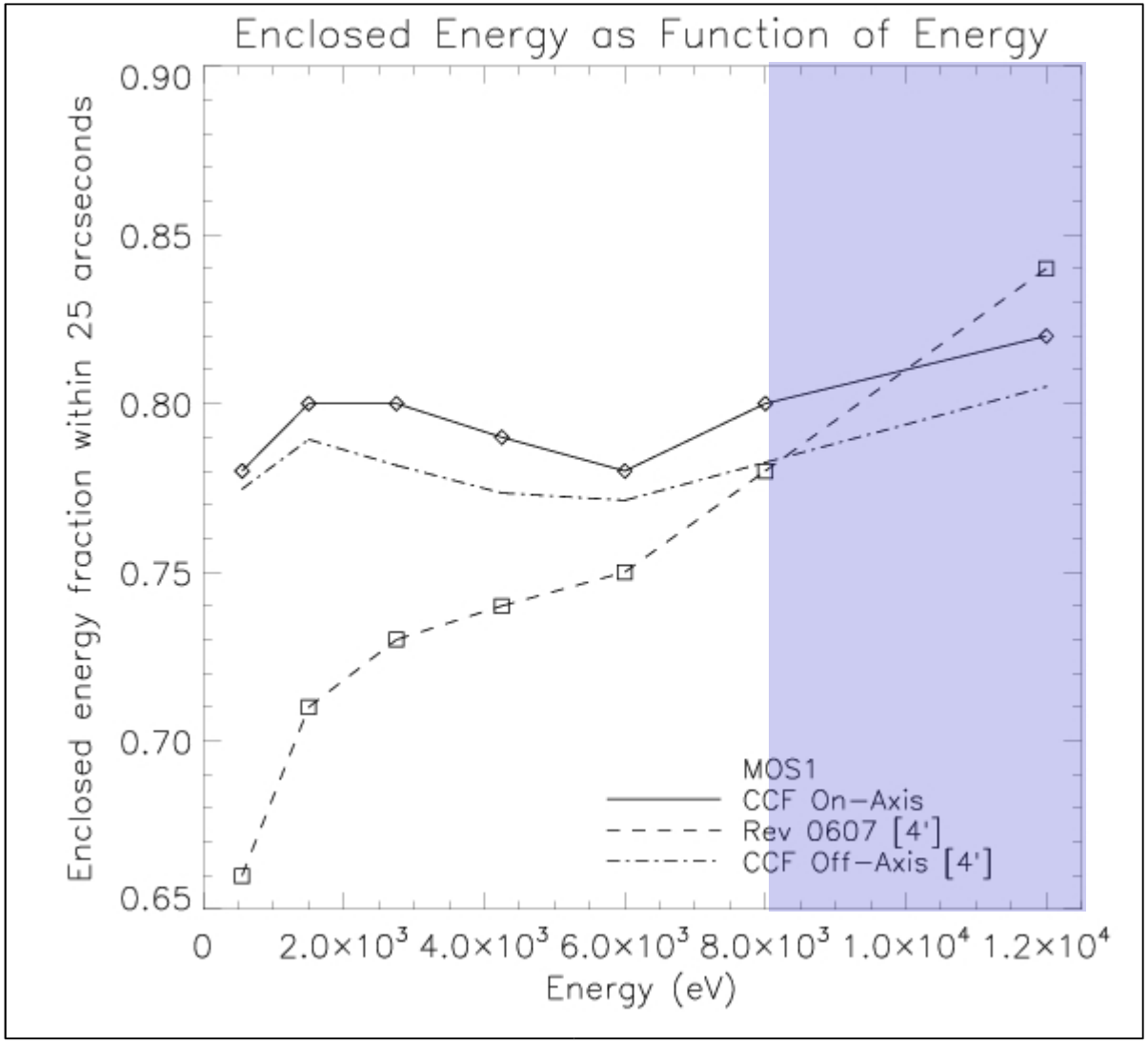
Can plot off-axis PSFs and compare with on-axis CCF PSFs

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

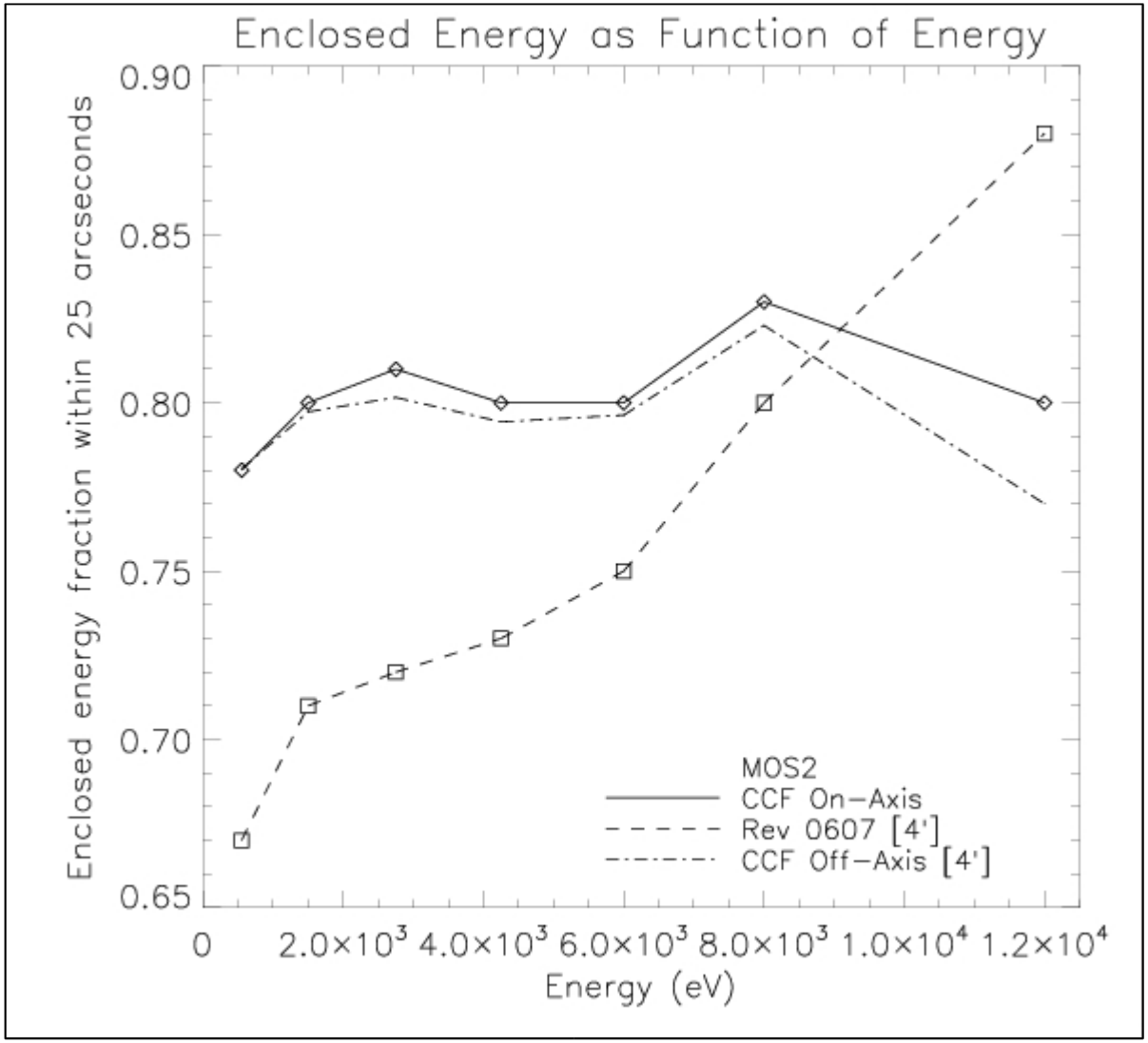


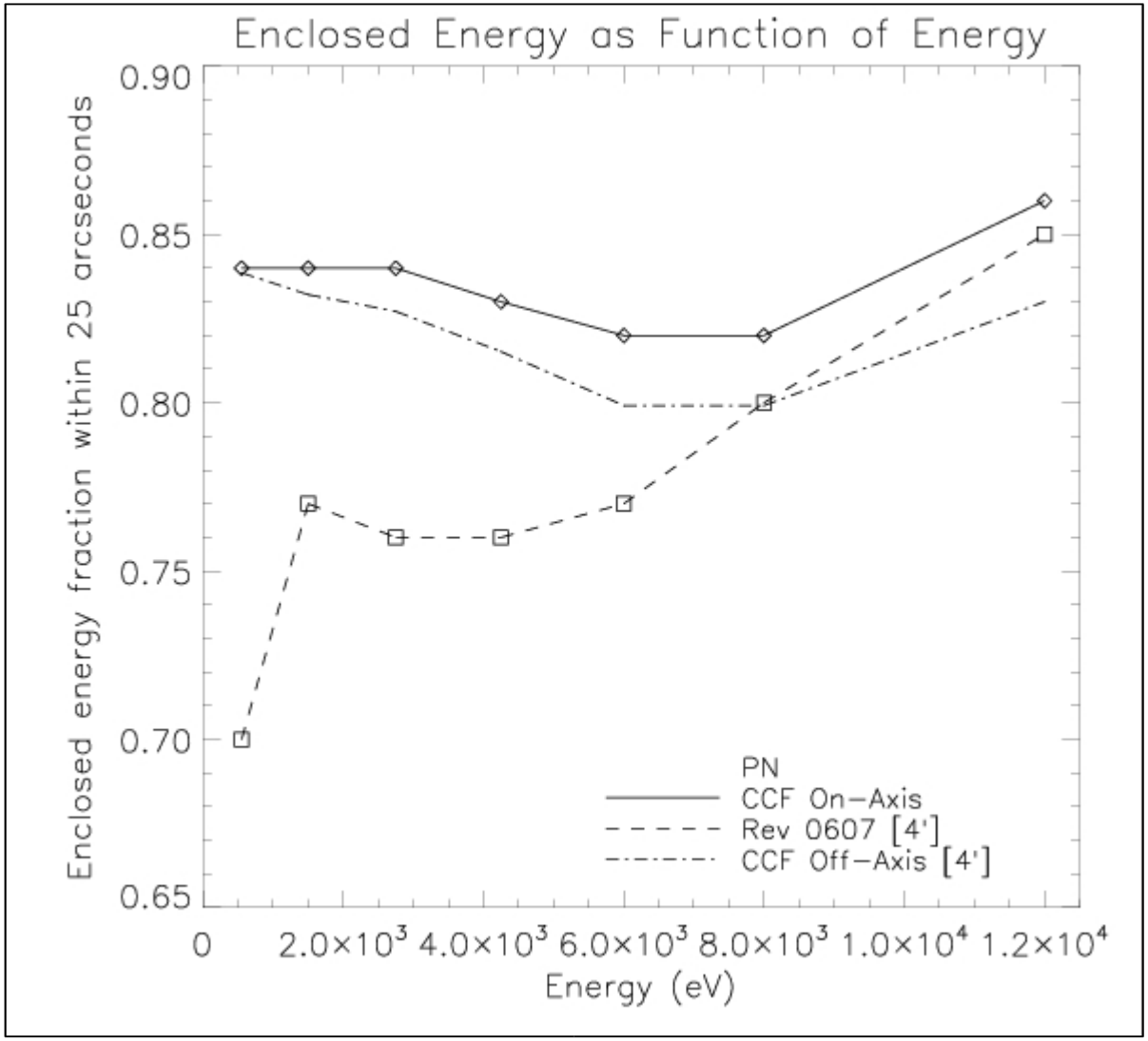
Can calculate enclosed energy as a function of energy…

University of Leicester



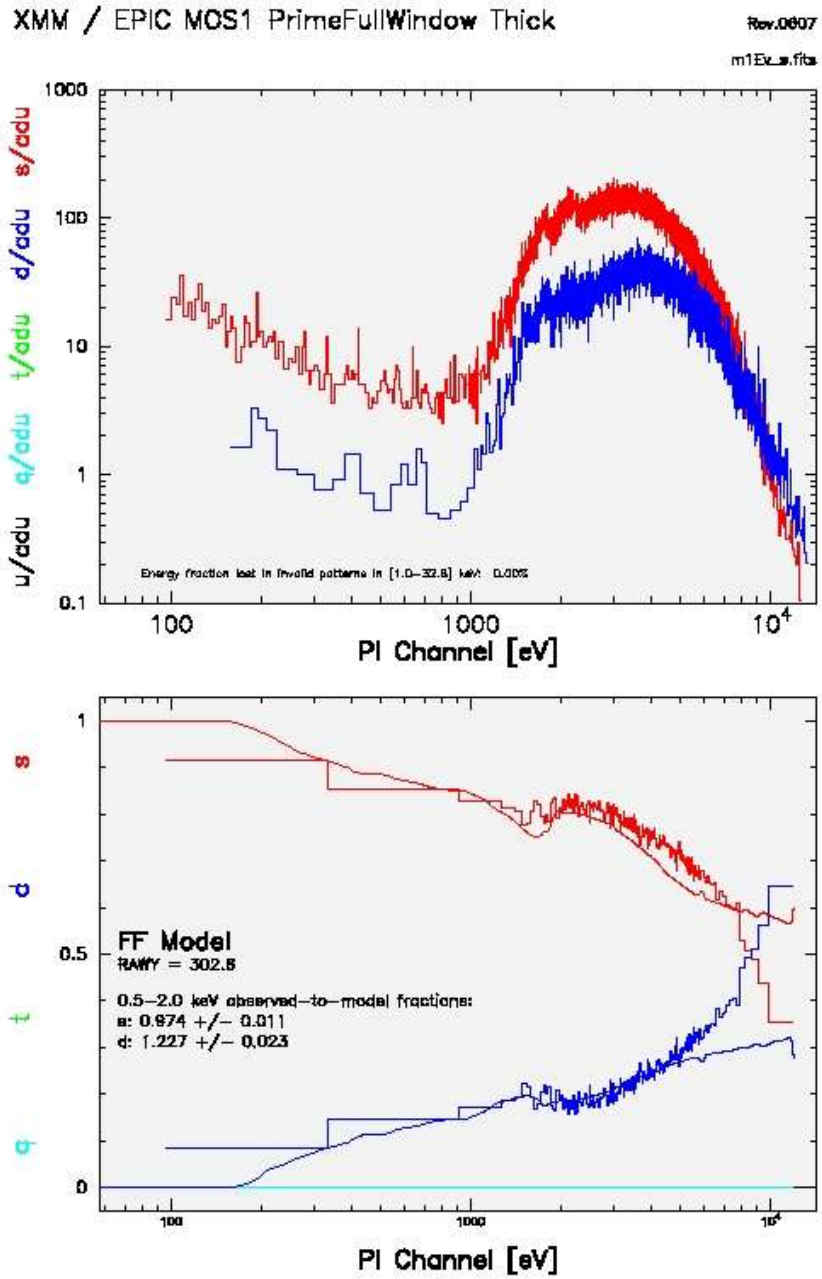
PSF parameters not very well determined at high-energy

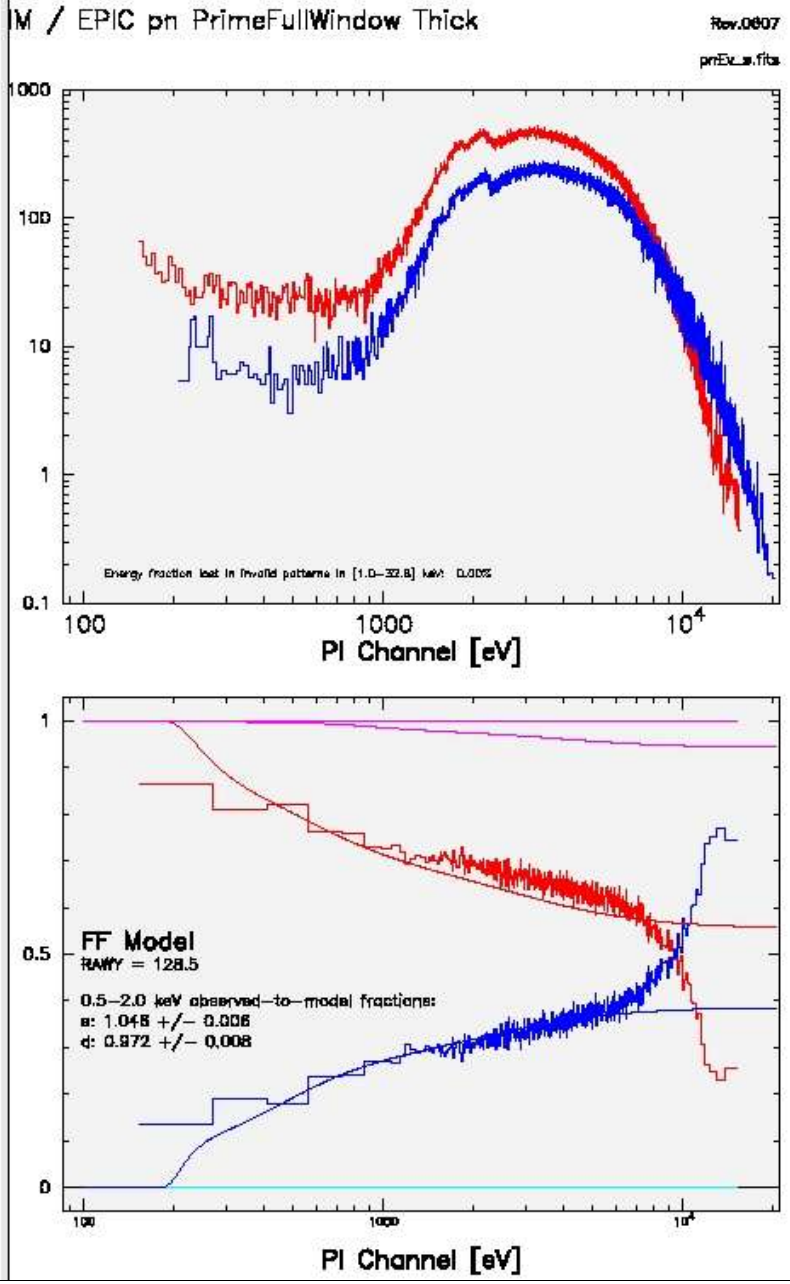

Enclosed Energy as Function of Energy
Enclosed energy fraction within 25 arcseconds
0.90
0.85
0.80
0.75
0.70
0.65
0
2.0×10³ 4.0×10³ 6.0×10³ 8.0×10³ 1.0×10⁴ 1.2×10⁴
Energy (eV)
MOS2
CCF On−Axis
Rev 0607 [4']
CCF Off−Axis [4']

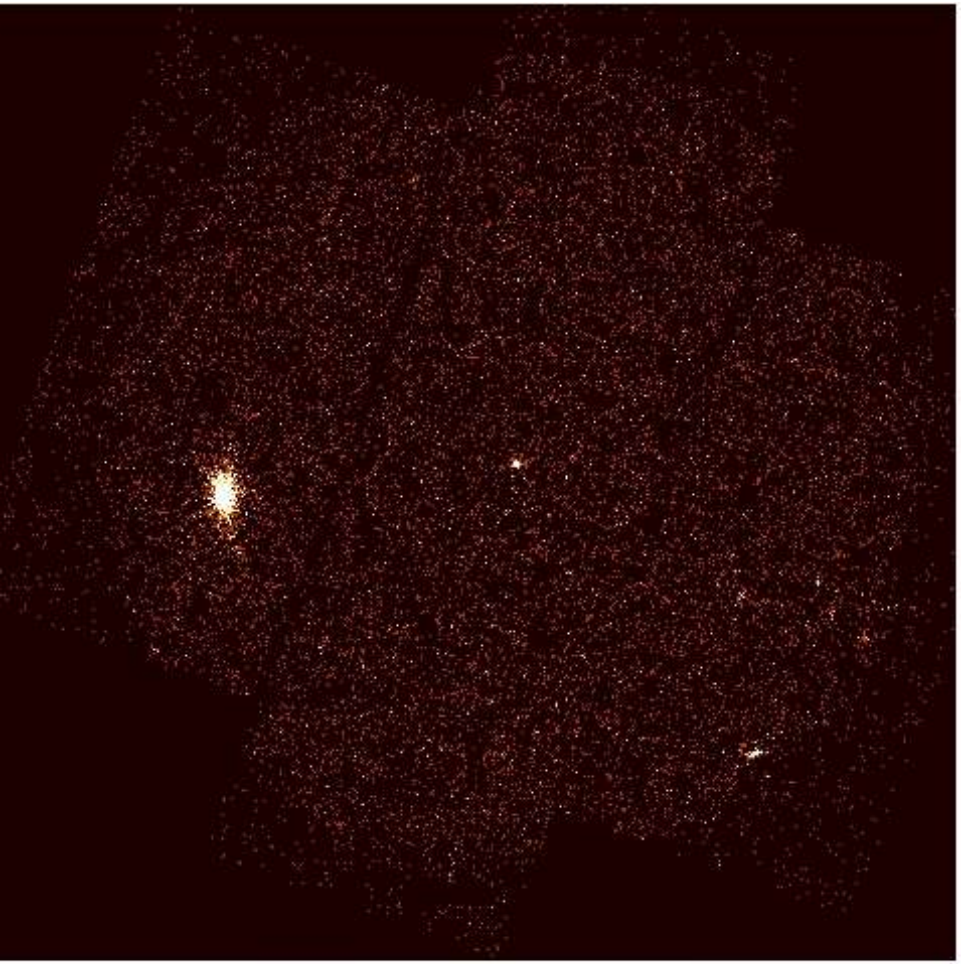


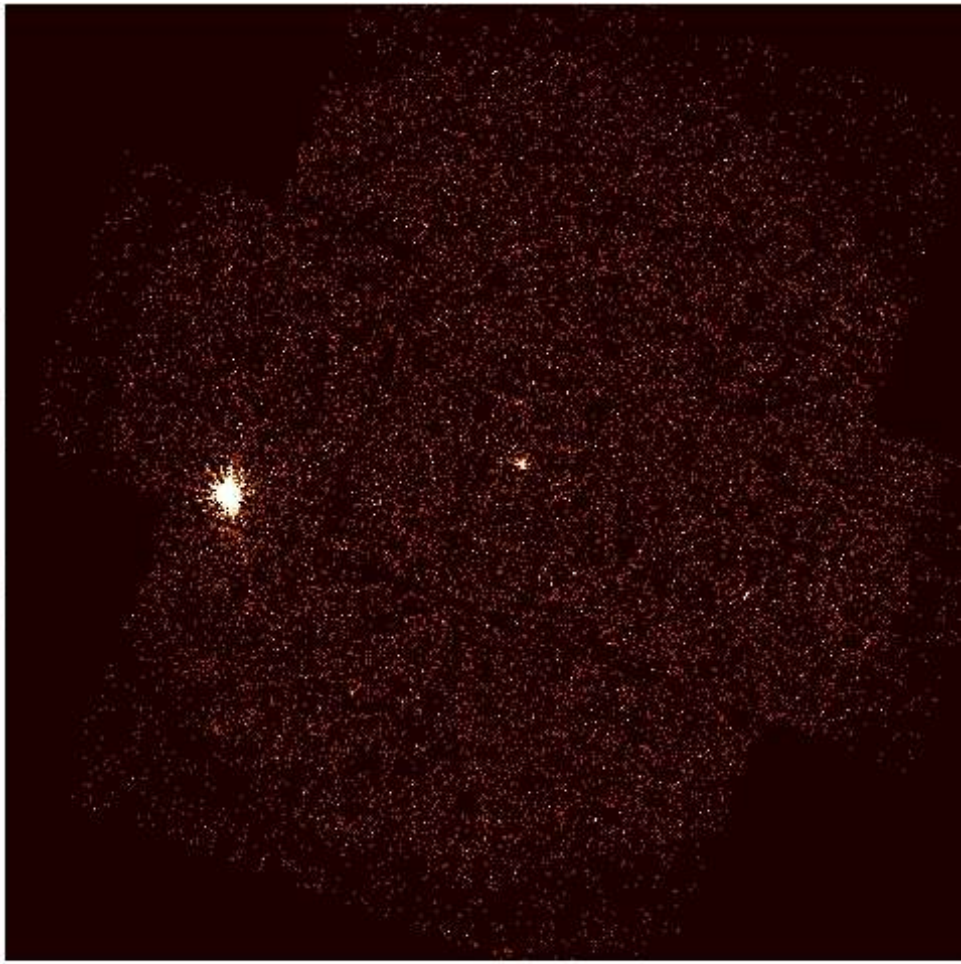
However, Source is quite piled-up!

- Need to investigate less piled-up sources


XMM / EPIC MOS1 PrimeFullWindow Thick
Rev.0607
m1Ev_s.fits
s/adu
d/adu
t/adu
q/adu
u/adu
Energy fraction lost in invalid patterns in [1.0–32.8] keV: 0.00%
PI Channel [eV]
FF Model
RAWY = 302.5
0.5–2.0 keV observed–to–model fractions:
s: 0.974 +/– 0.011
d: 1.227 +/– 0.023
PI Channel [eV]


M / EPIC pn PrimeFullWindow Thick
Rev.0607
pnEv_s.fits
Energy fraction lost in invalid patterns in [1.0–32.8] keV: 0.00%
PI Channel [eV]
FF Model
RAWY = 128.5
0.5–2.0 keV observed–to–model fractions:
s: 1.045 +/– 0.006
d: 0.972 +/– 0.008
PI Channel [eV]





NGC7603 10 arcmin off-axis

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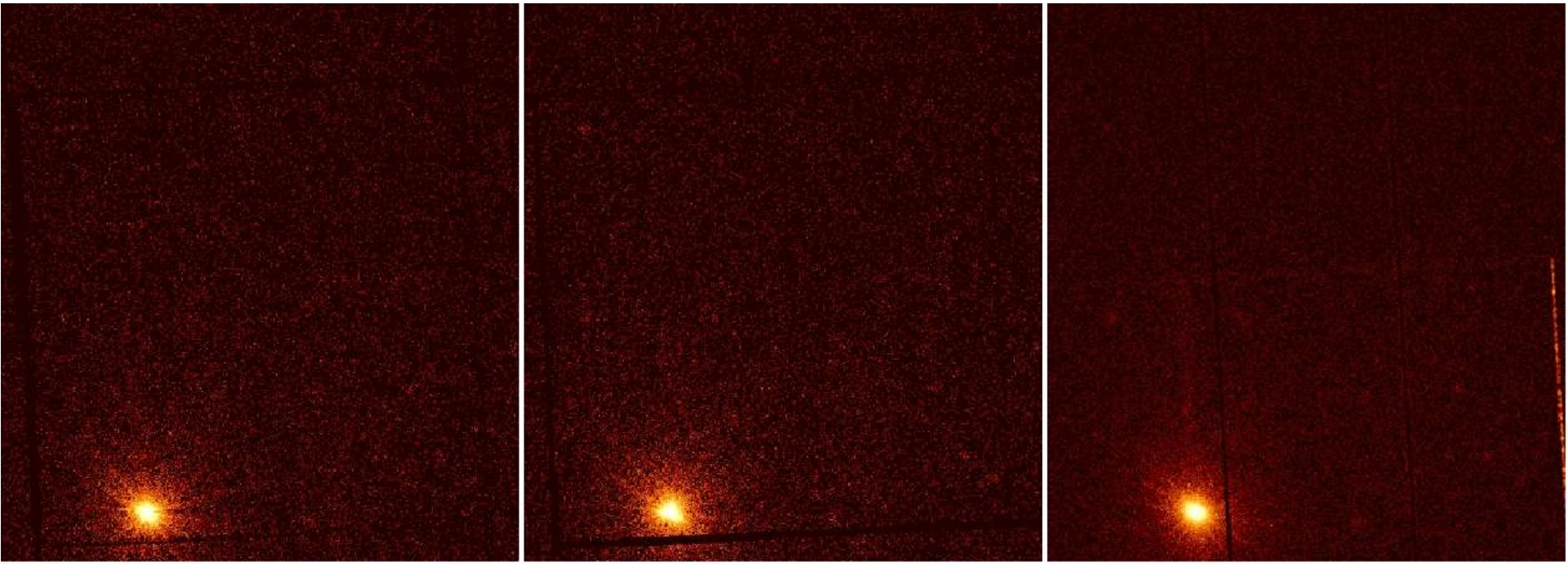


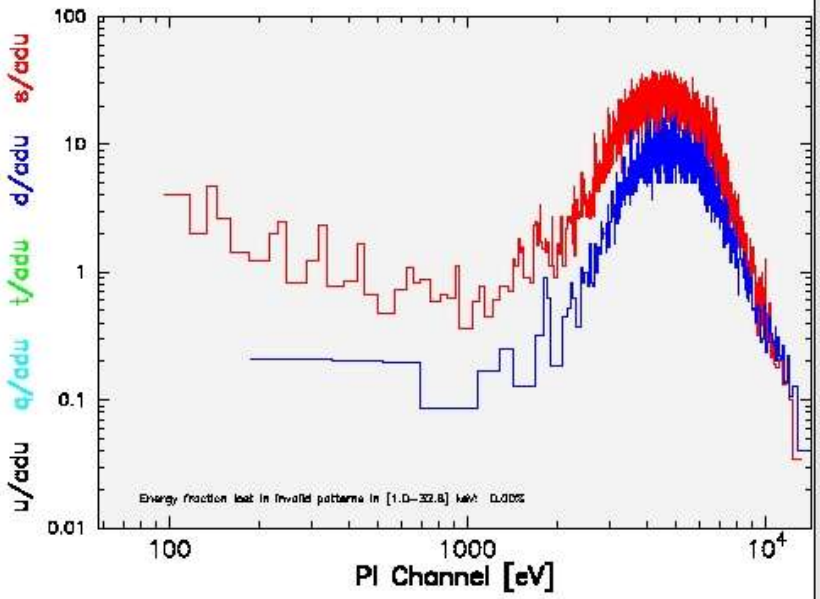
AX J1746.3-2843 5.5 arcmin off-axis ~ 30ksec

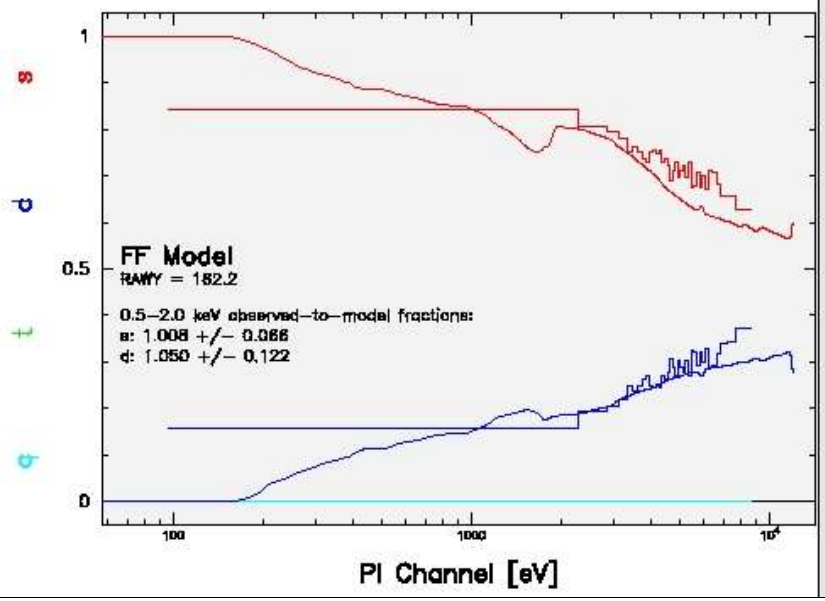
Andy Read (amr30@star.le.ac.uk)

XMM / EPIC MOS1 PrimeFullWindow Medium

Rev.0143

m1Ev_a.fits

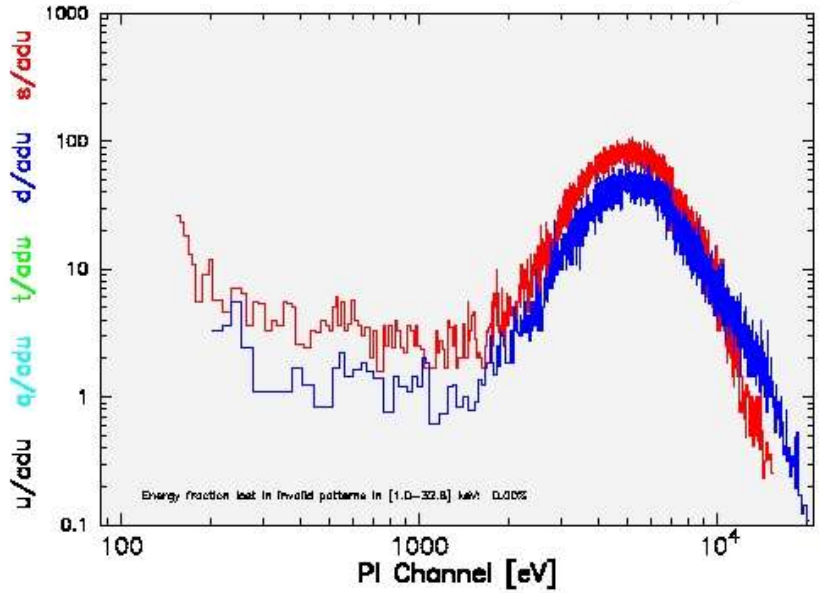


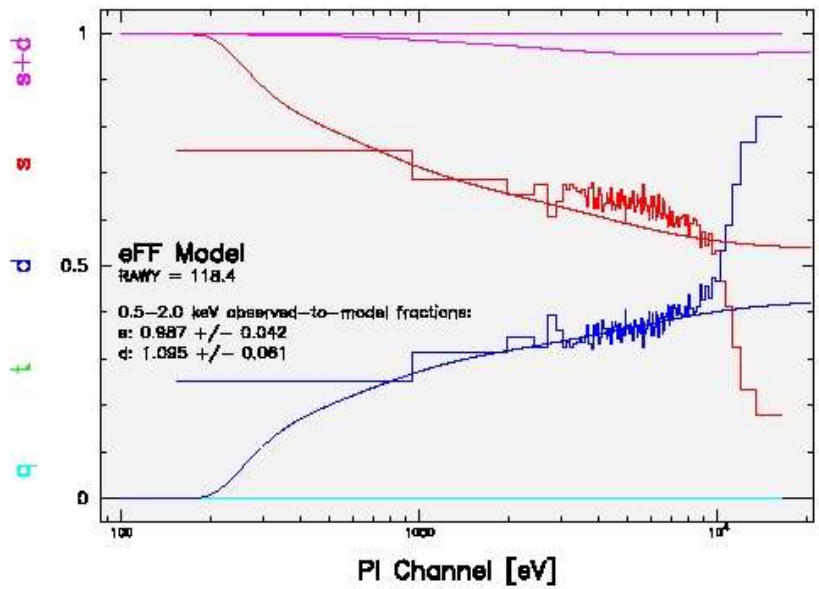


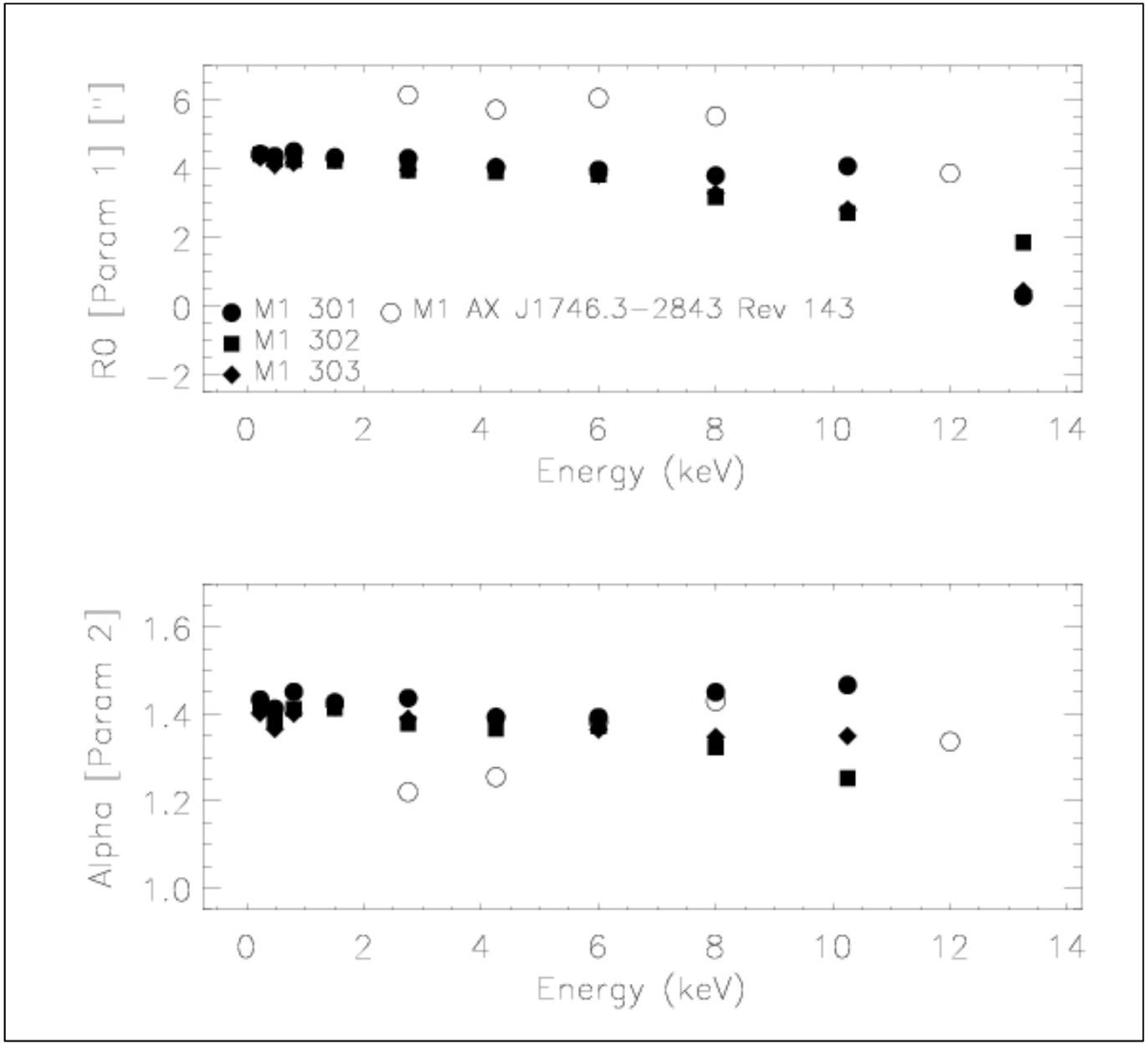
XMM / EPIC pn PrimeFullWindowExtended Medium

Rev.0143

pnEv_a.fits



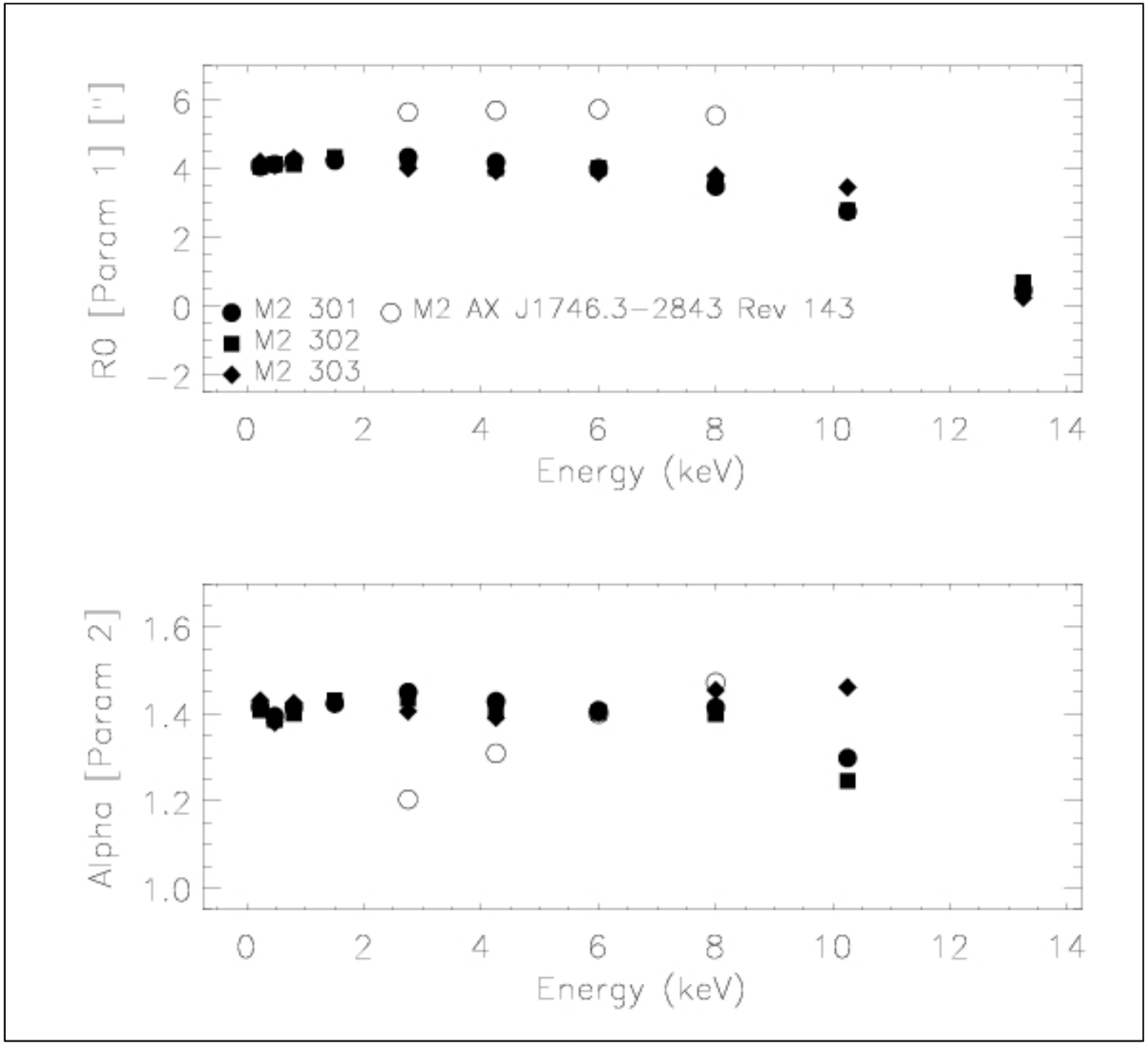


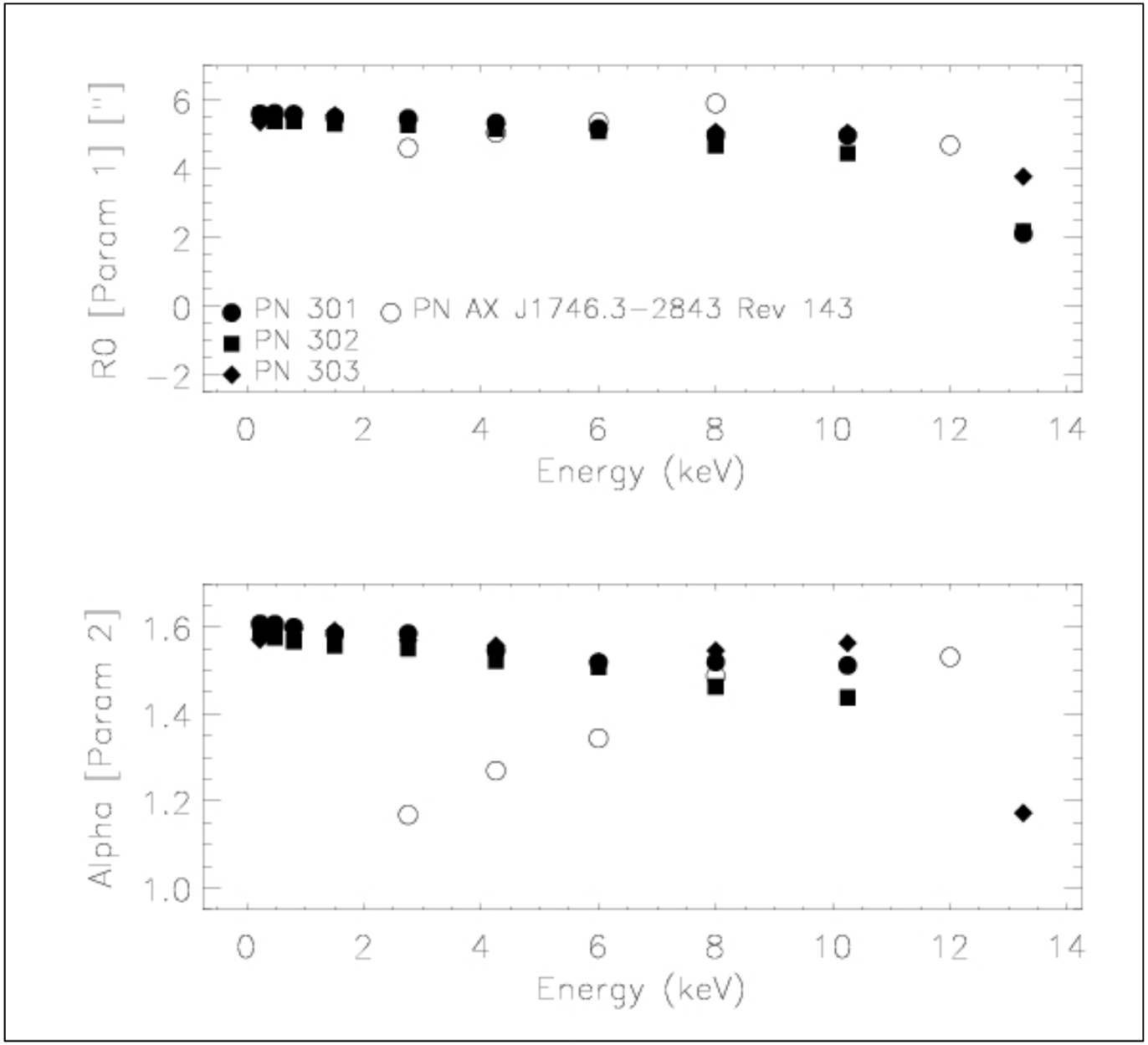


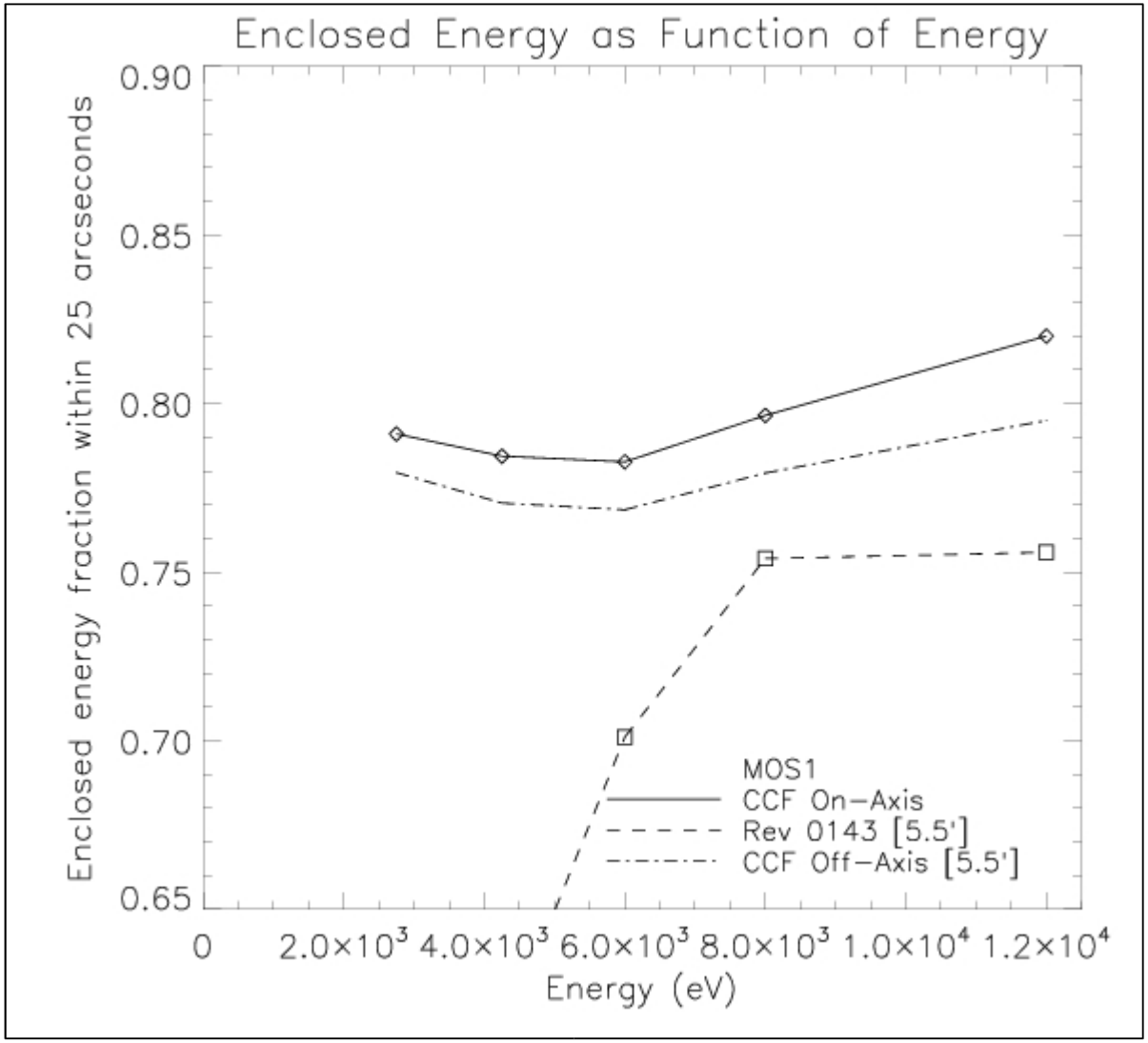
Source is very hard –

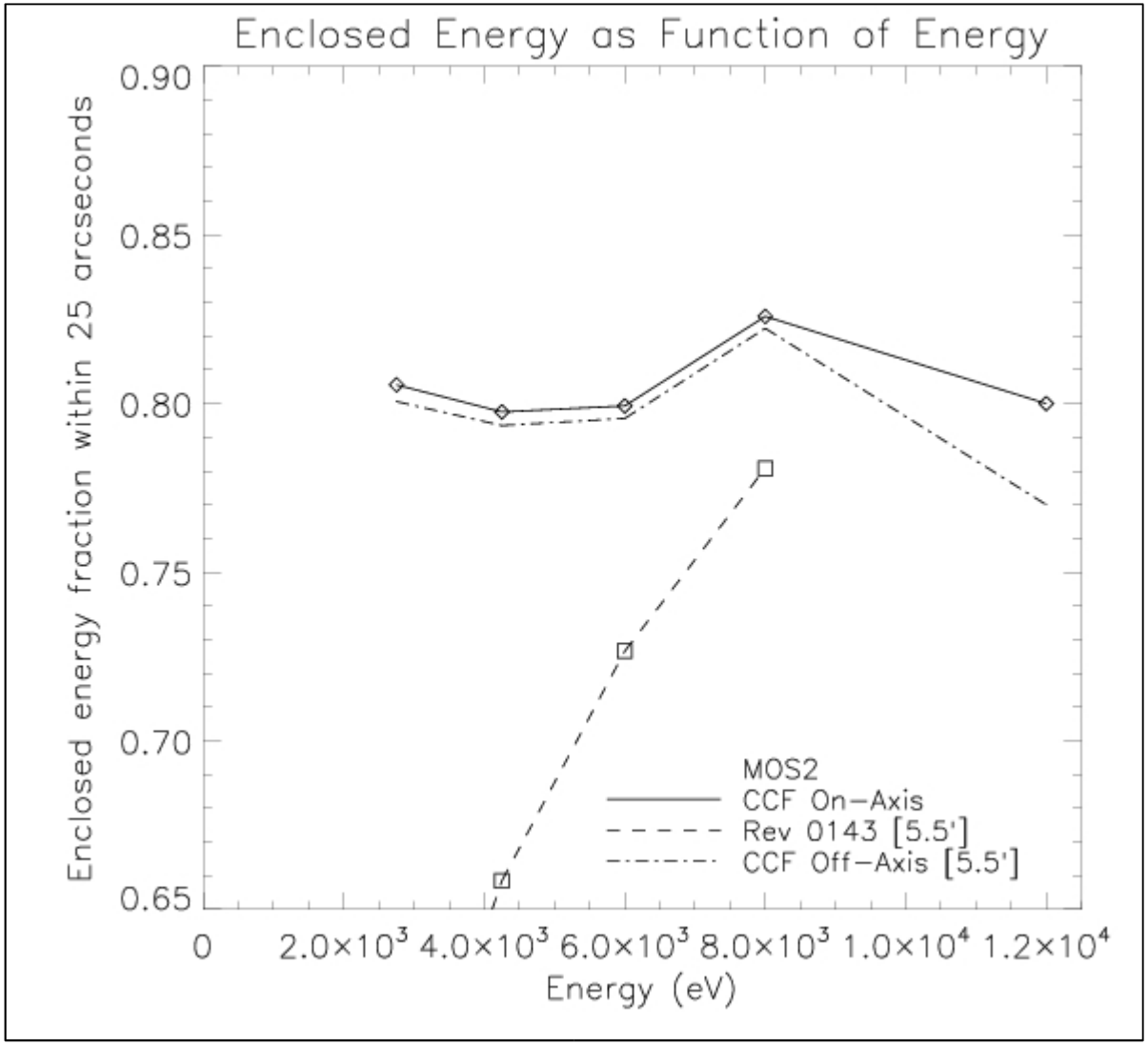
No information below ~2keV, but can obtain high-energy PSFs

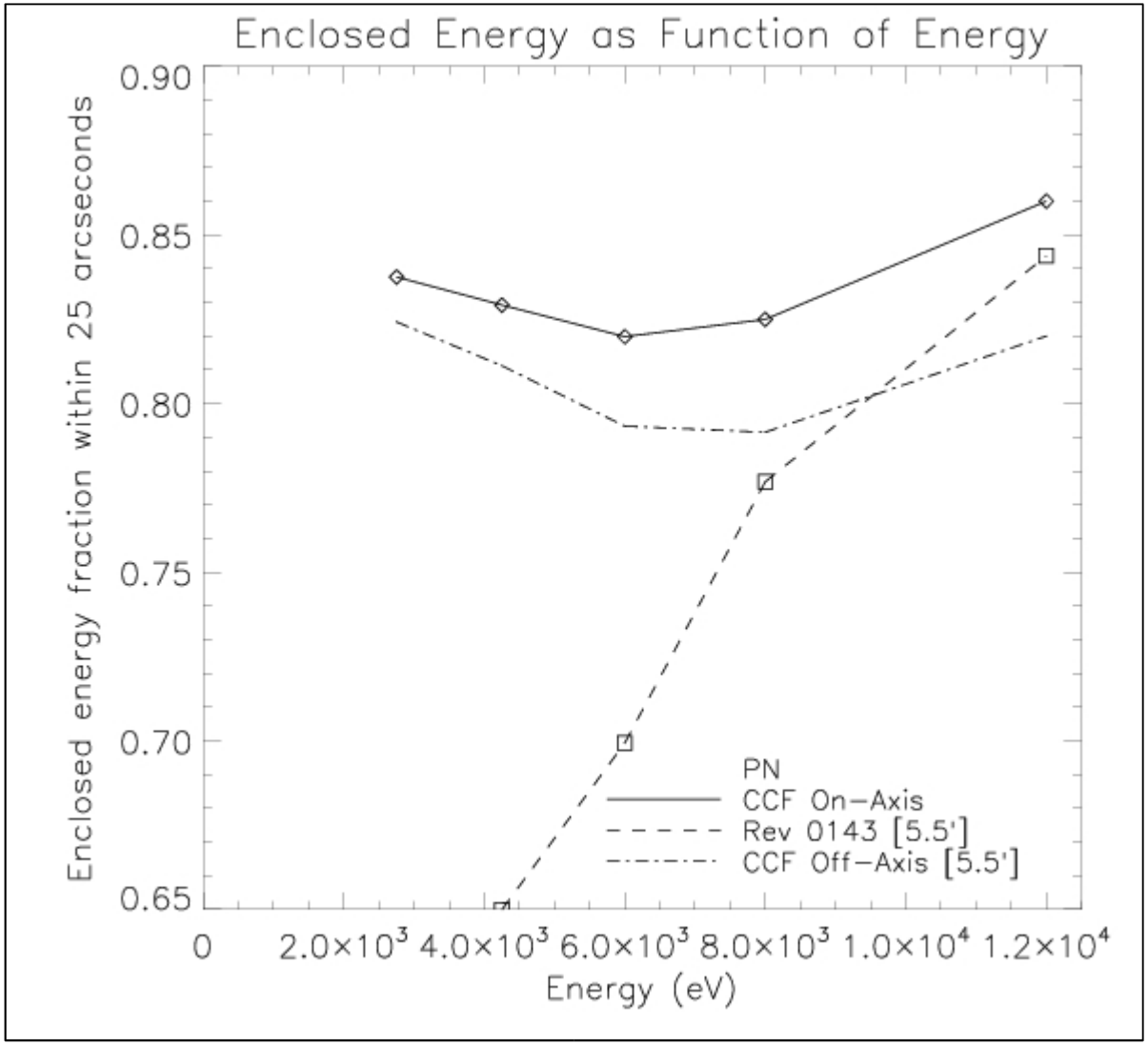
- Again, different behaviour from on-axis PSFs


R0 [Param 1] ['']
6
4
2
0
−2
M2 301
M2 302
M2 303
M2 AX J1746.3−2843 Rev 143
0
2
4
6
8
10
12
14
Energy (keV)
Alpha [Param 2]
1.6
1.4
1.2
1.0
0
2
4
6
8
10
12
14
Energy (keV)


R0 [Param 1] ['']
6
4
2
0
−2
PN 301
PN 302
PN 303
PN AX J1746.3−2843 Rev 143
0
2
4
6
8
10
12
14
Energy (keV)
Alpha [Param 2]
1.6
1.4
1.2
1.0
0
2
4
6
8
10
12
14
Energy (keV)

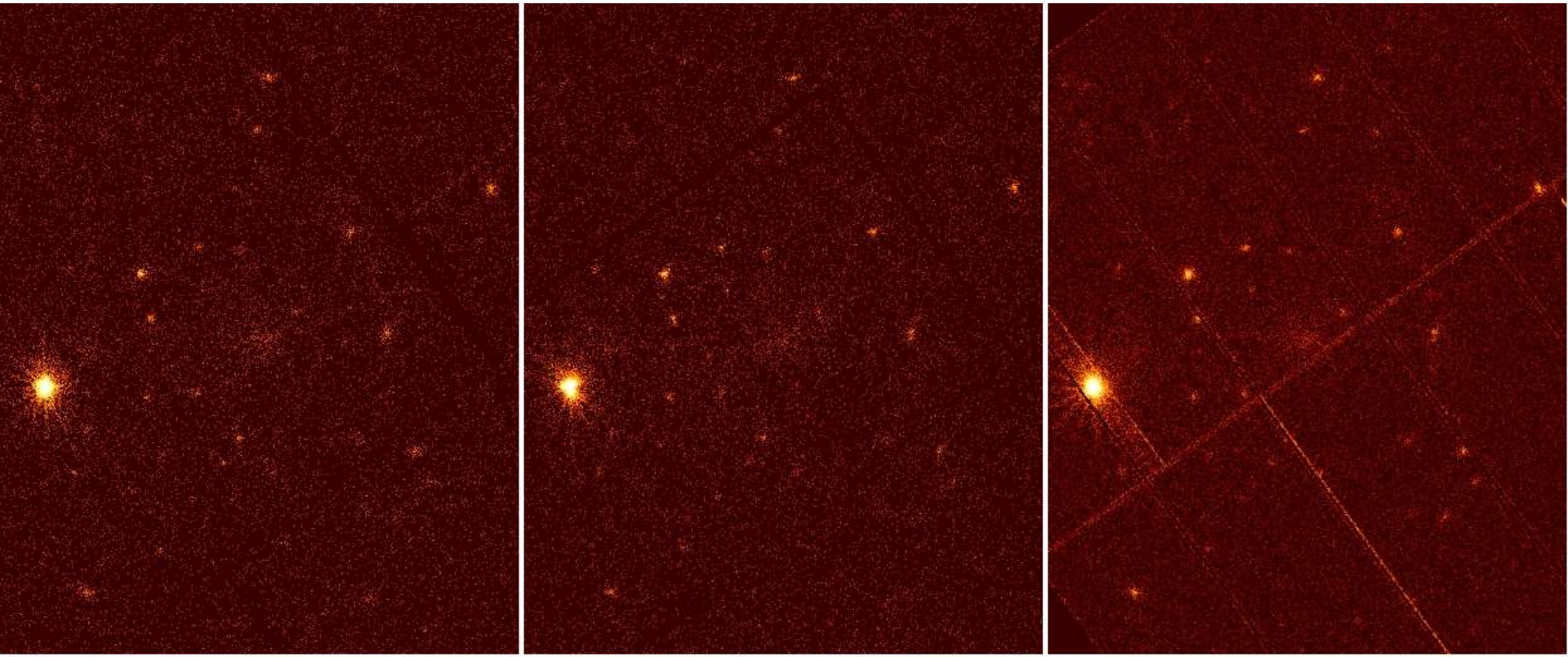

Enclosed Energy as Function of Energy
Enclosed energy fraction within 25 arcseconds
0.90
0.85
0.80
0.75
0.70
0.65
0
2.0×10³ 4.0×10³ 6.0×10³ 8.0×10³ 1.0×10⁴ 1.2×10⁴
Energy (eV)
MOS1
CCF On−Axis
Rev 0143 [5.5']
CCF Off−Axis [5.5']


Enclosed Energy as Function of Energy
Enclosed energy fraction within 25 arcseconds
0.90
0.85
0.80
0.75
0.70
0.65
0
2.0×10³ 4.0×10³ 6.0×10³ 8.0×10³ 1.0×10⁴ 1.2×10⁴
Energy (eV)
MOS2
CCF On−Axis
Rev 0143 [5.5']
CCF Off−Axis [5.5']



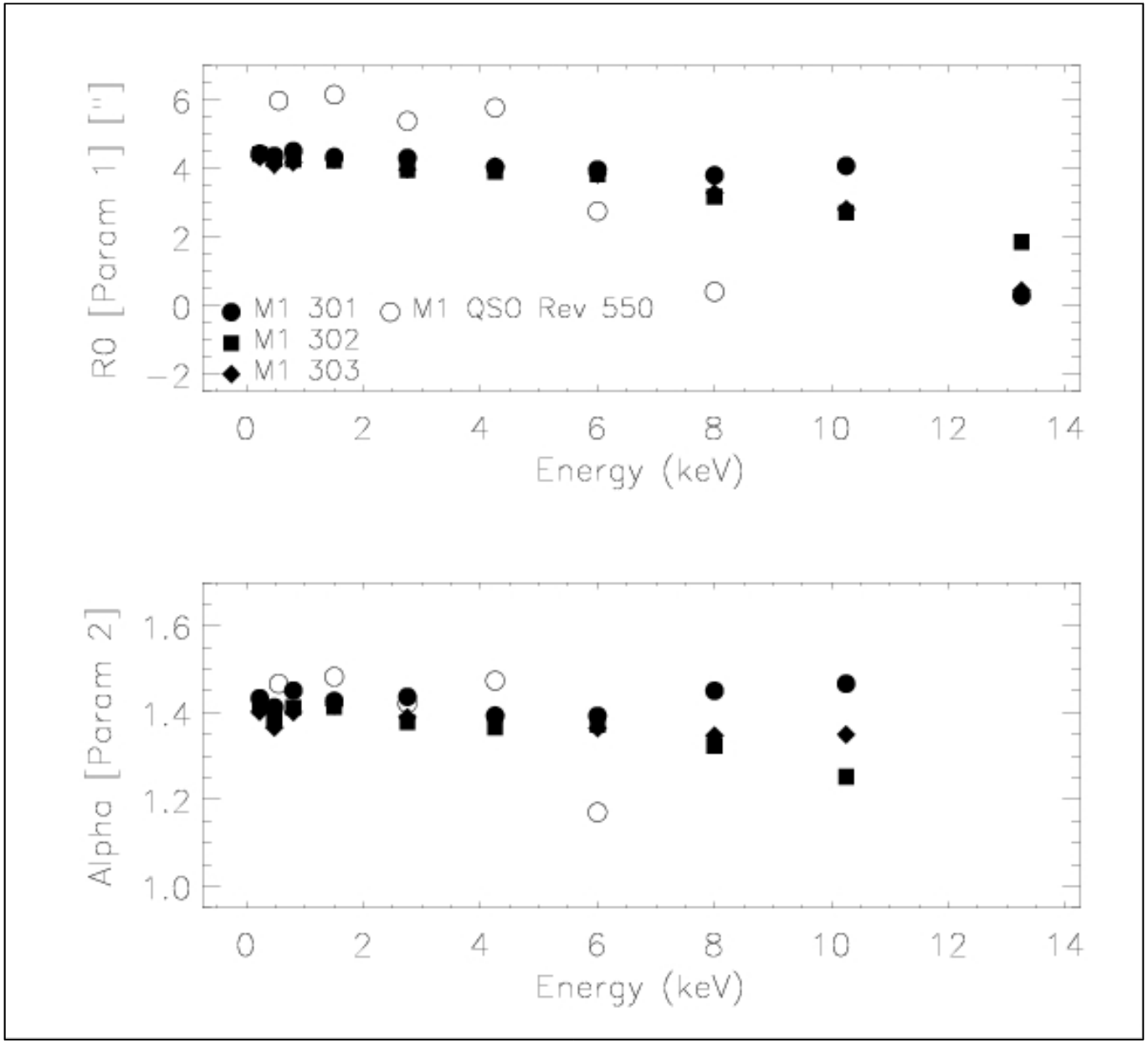
Source is not particularly piled-up

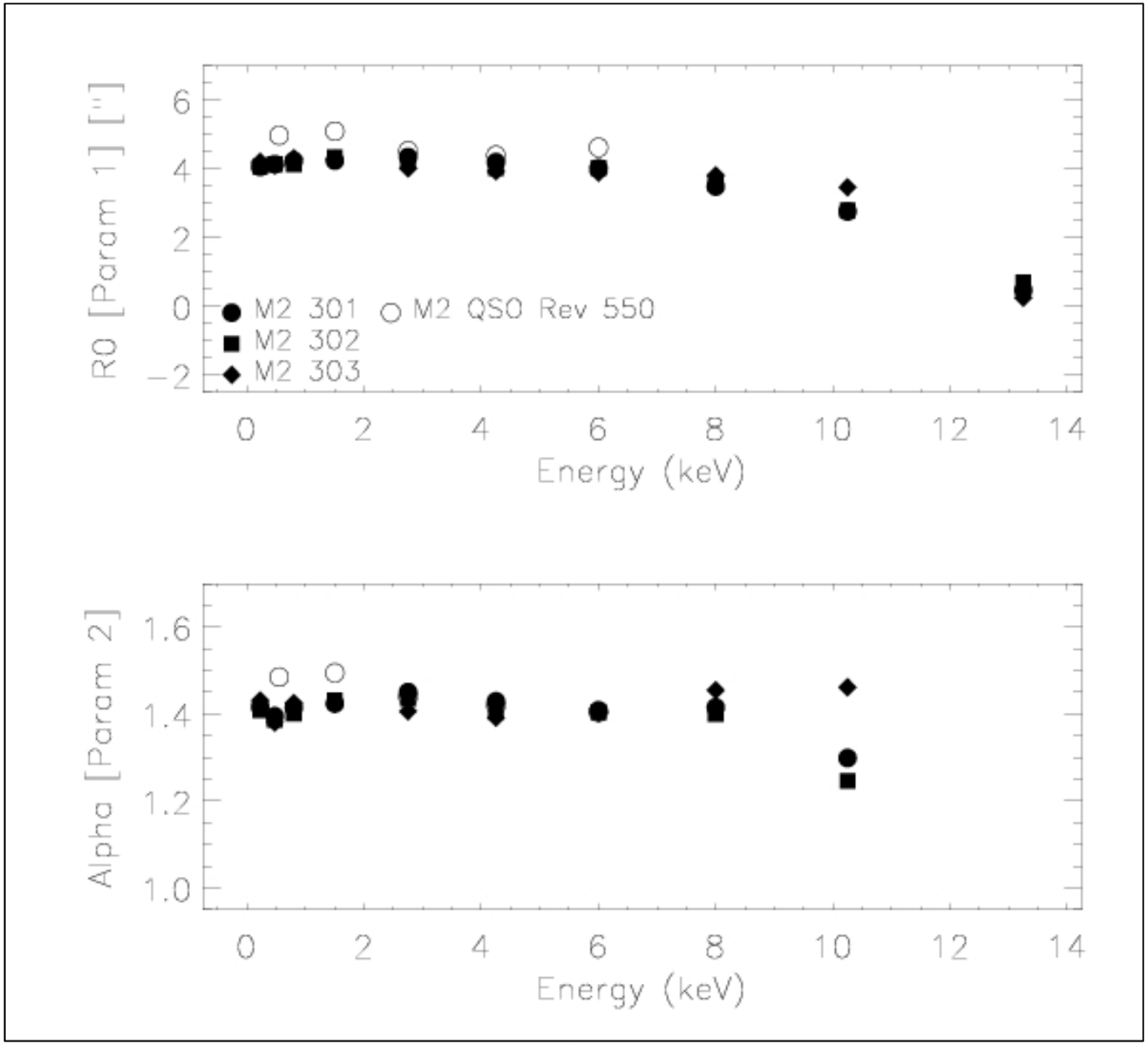
Source is very slightly extended? – added complication

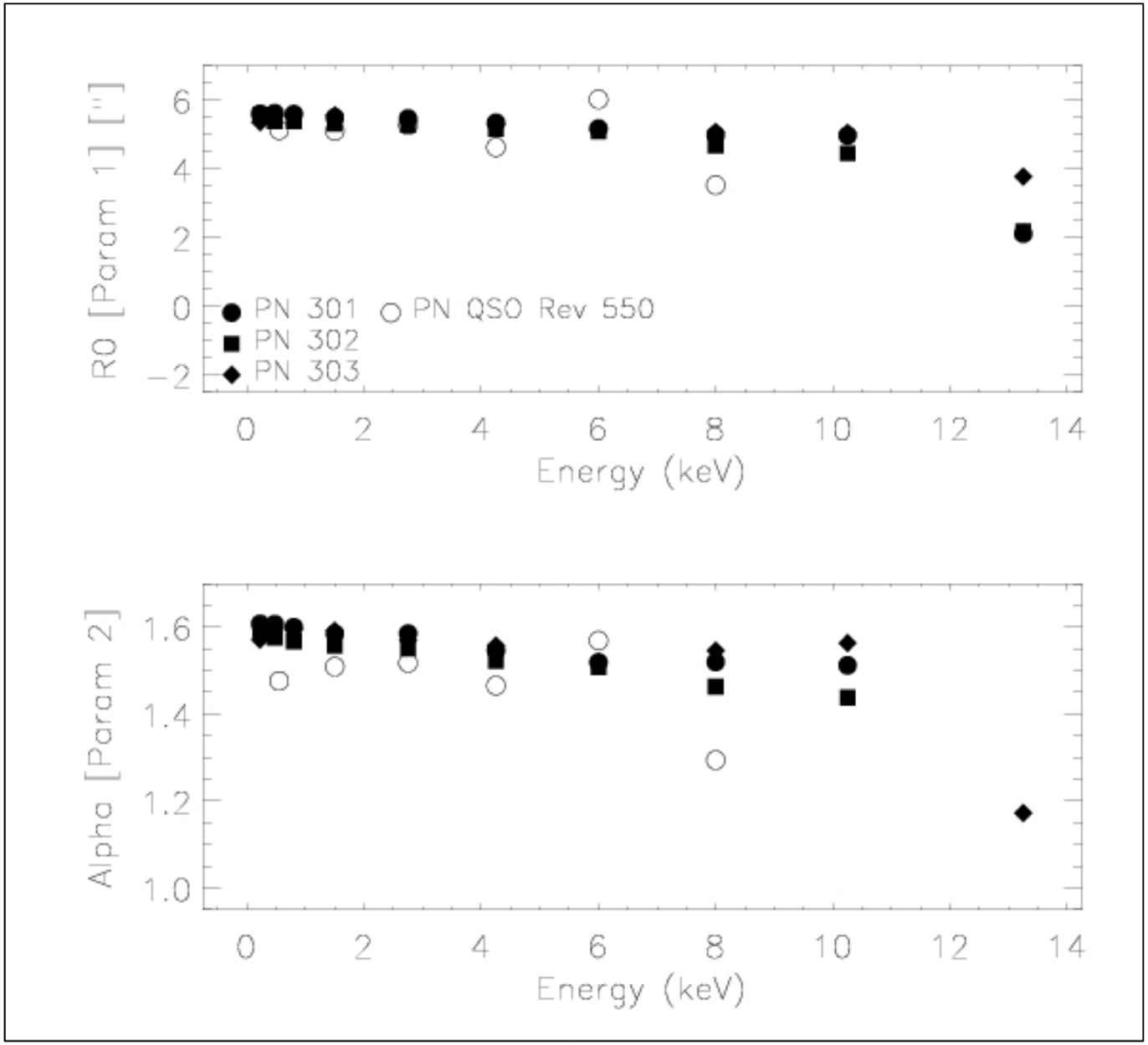


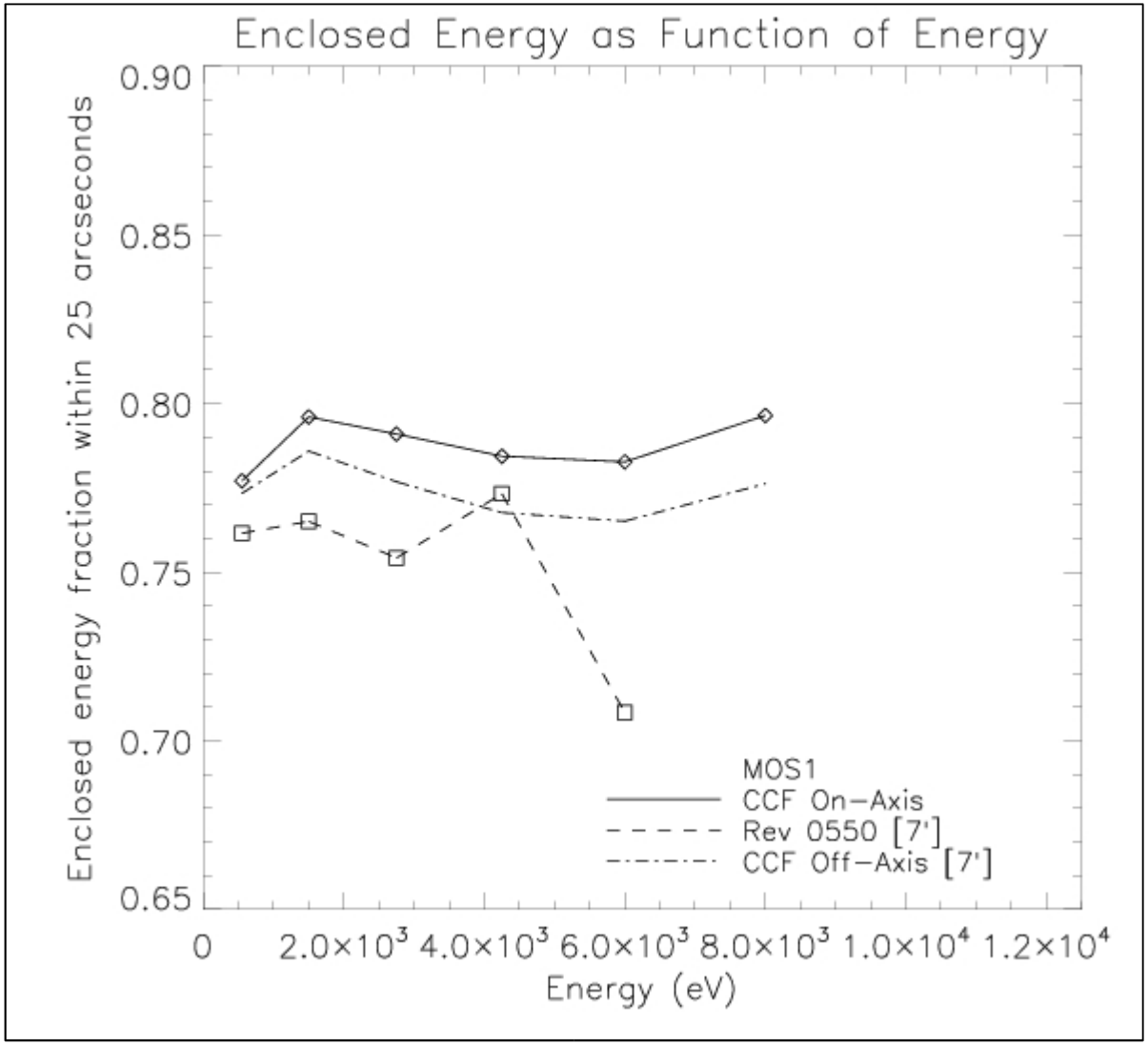
QSO 1308+326 7 arcmin off-axis ~50 ksec clean FF data

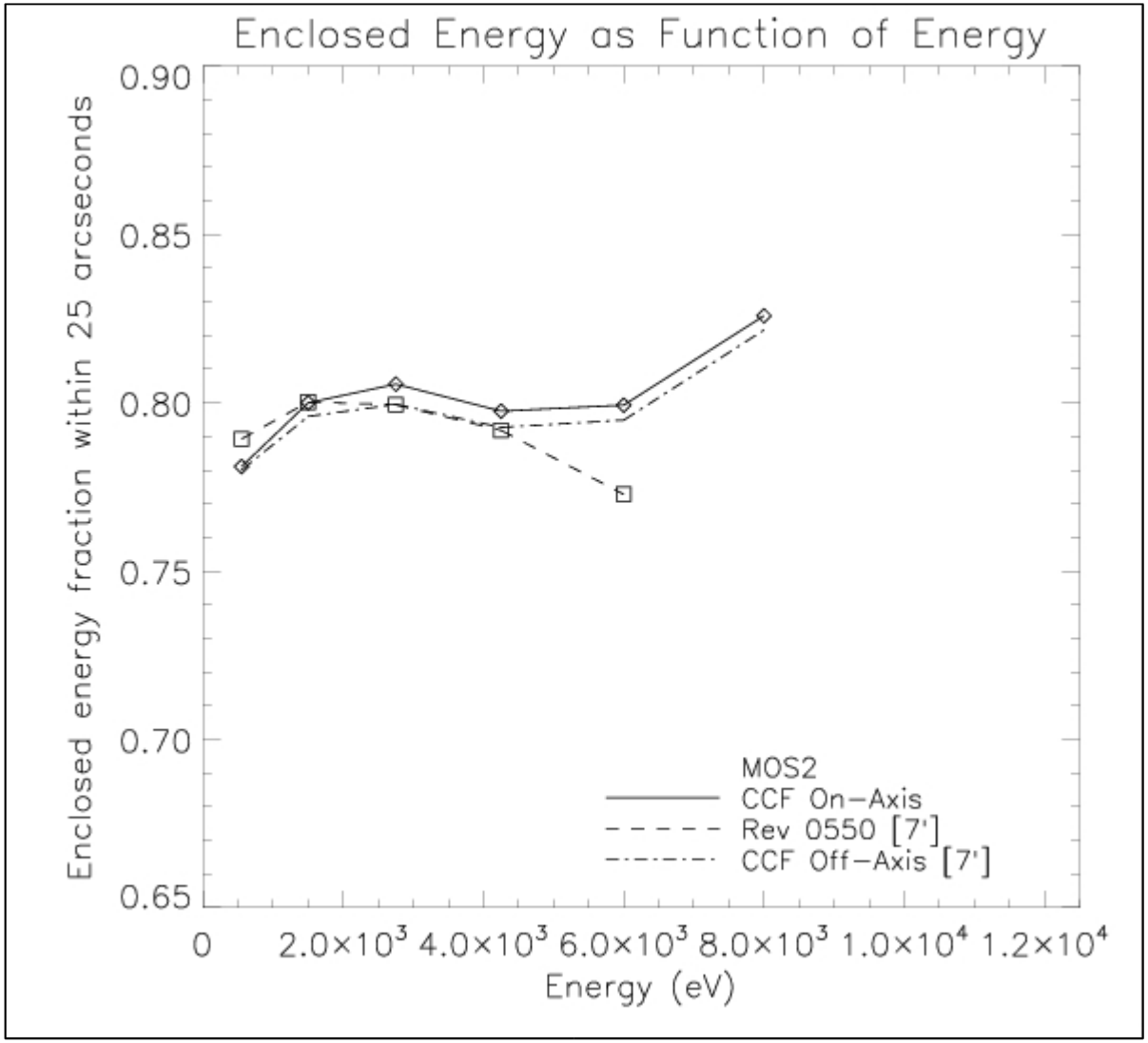
Andy Read (amr30@star.le.ac.uk)

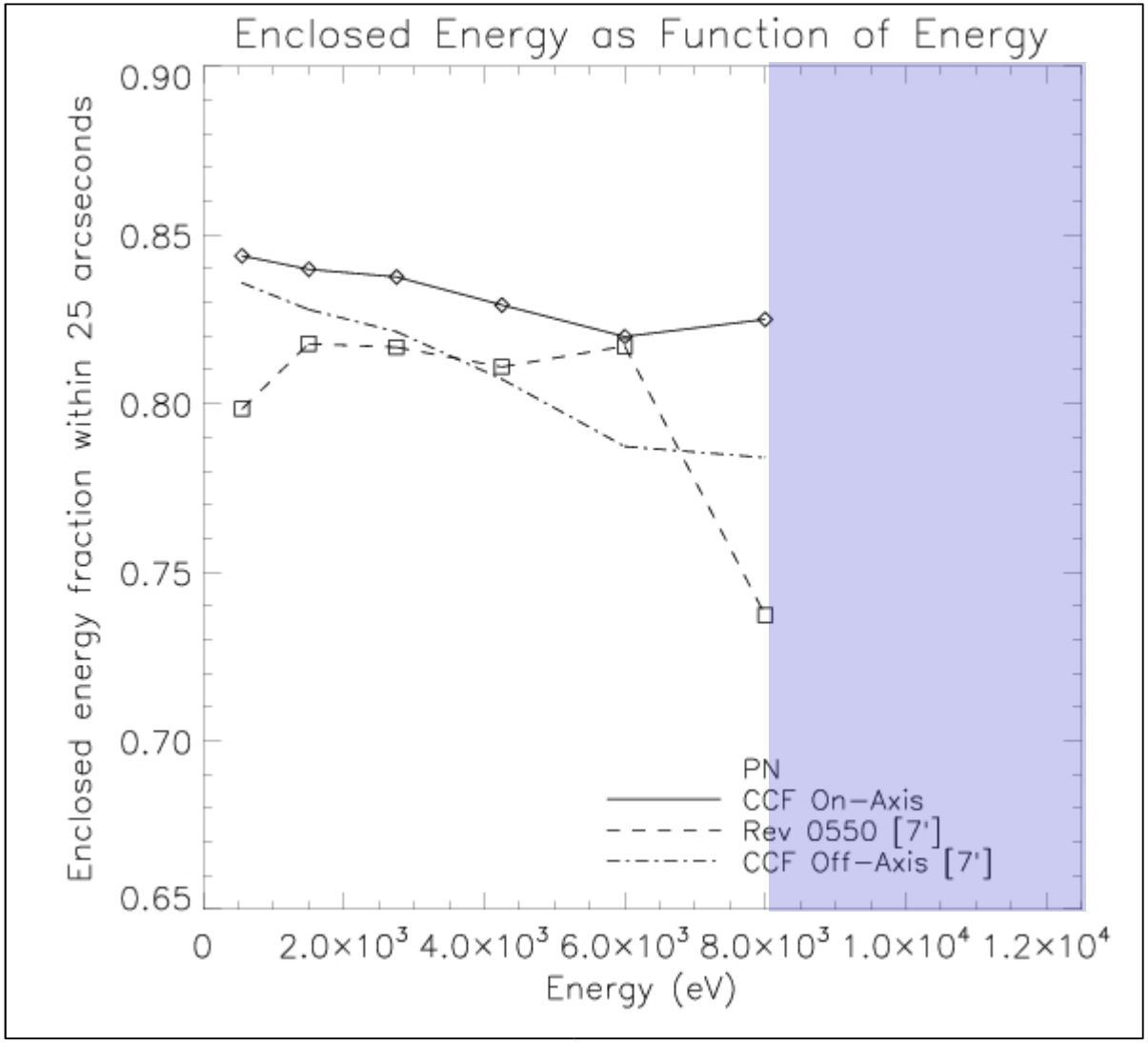

R0 [Param 1] ['']
6
4
2
0
−2
M1 301
M1 302
M1 303
M1 QSO Rev 550
0
2
4
6
8
10
12
14
Energy (keV)
Alpha [Param 2]
1.6
1.4
1.2
1.0
0
2
4
6
8
10
12
14
Energy (keV)


R0 [Param 1] ['']
6
4
2
0
−2
M2 301
M2 302
M2 303
M2 QSO Rev 550
0
2
4
6
8
10
12
14
Energy (keV)
Alpha [Param 2]
1.6
1.4
1.2
1.0
0
2
4
6
8
10
12
14
Energy (keV)


R0 [Param 1] ['']
6
4
2
0
−2
PN 301
PN 302
PN 303
PN QSO Rev 550
0
2
4
6
8
10
12
14
Energy (keV)
Alpha [Param 2]
1.6
1.4
1.2
1.0
0
2
4
6
8
10
12
14
Energy (keV)


Enclosed Energy as Function of Energy
Enclosed energy fraction within 25 arcseconds
0.90
0.85
0.80
0.75
0.70
0.65
0
2.0×10³ 4.0×10³ 6.0×10³ 8.0×10³ 1.0×10⁴ 1.2×10⁴
Energy (eV)
MOS1
CCF On−Axis
Rev 0550 [7']
CCF Off−Axis [7']


Enclosed Energy as Function of Energy
Enclosed energy fraction within 25 arcseconds
0.90
0.85
0.80
0.75
0.70
0.65
0
2.0×10³ 4.0×10³ 6.0×10³ 8.0×10³ 1.0×10⁴ 1.2×10⁴
Energy (eV)
MOS2
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 (moreso 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.

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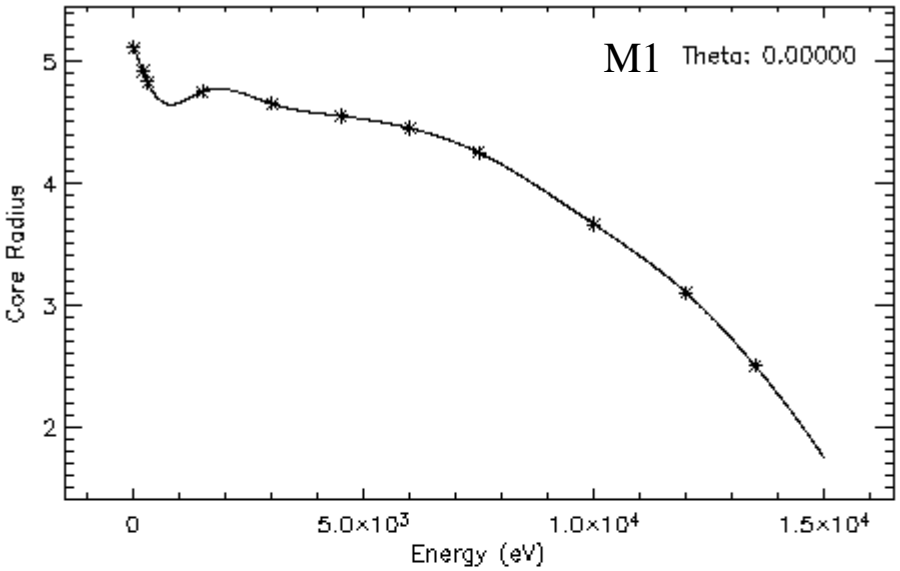
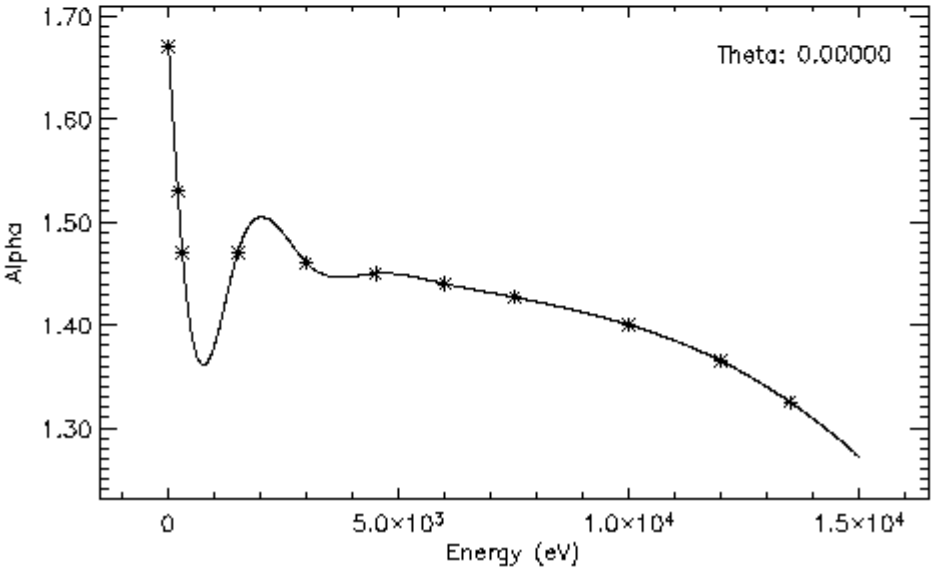
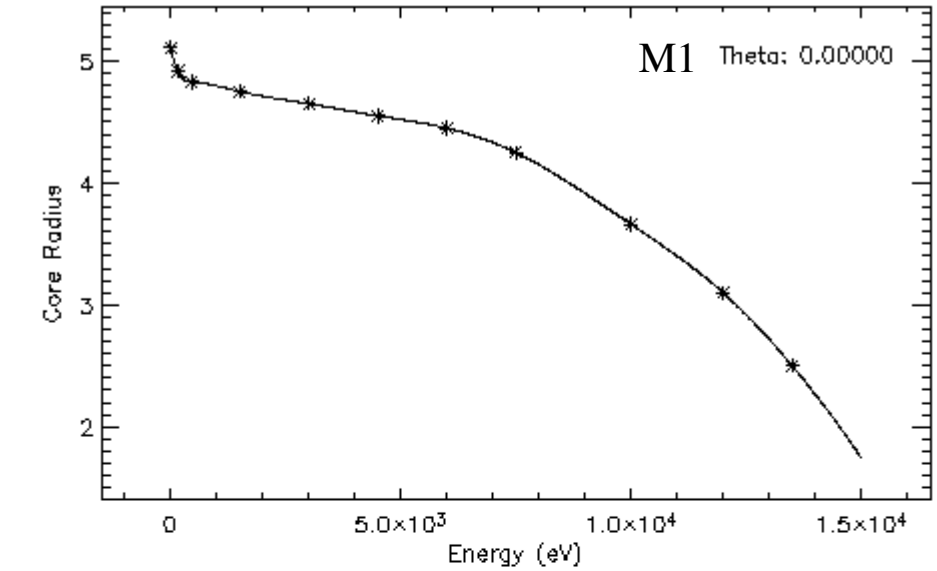
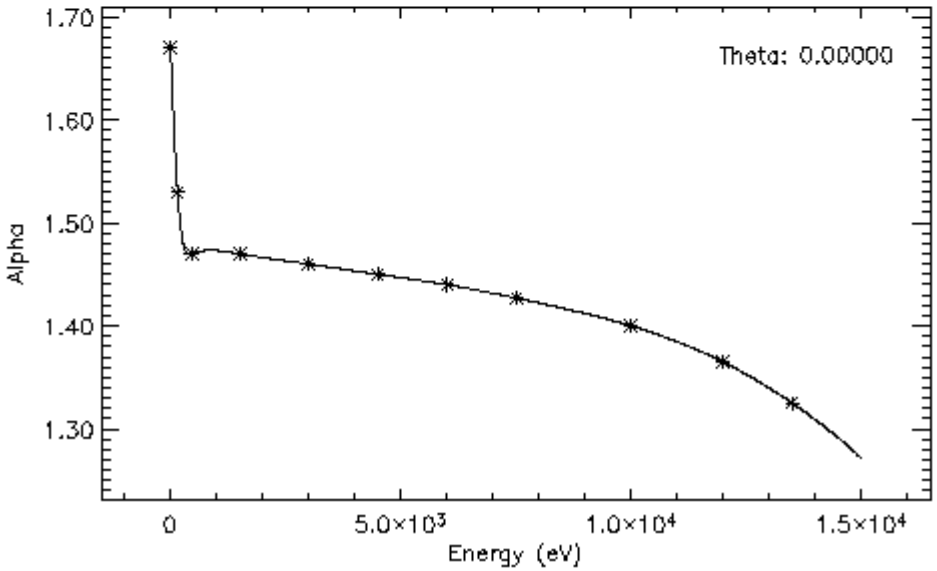




- Large/sudden changes in parameters can lead to very large, unrealistic extrapolated values
- Analysis shows that spline fitting to points also has gross effects far from region of large changes (here, at very low-E)

- 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

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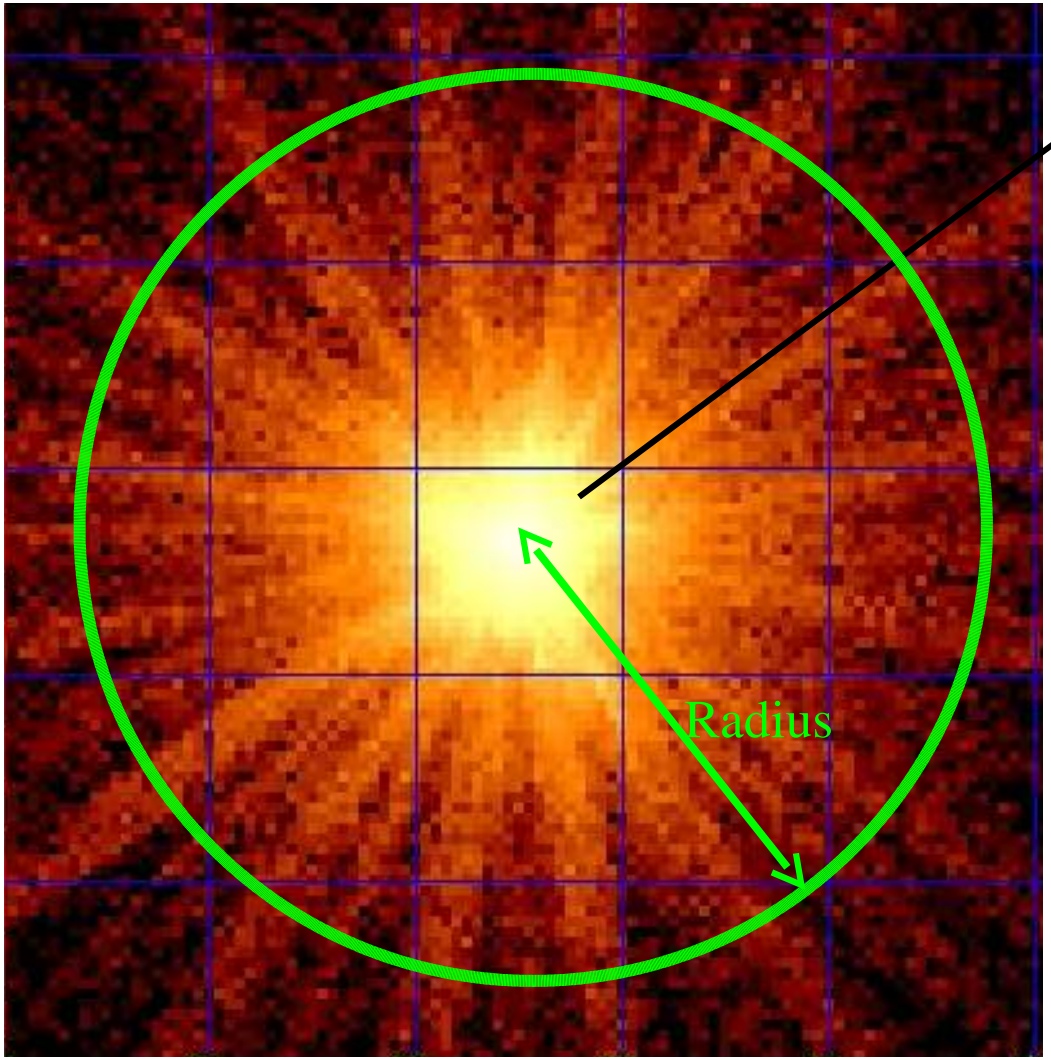
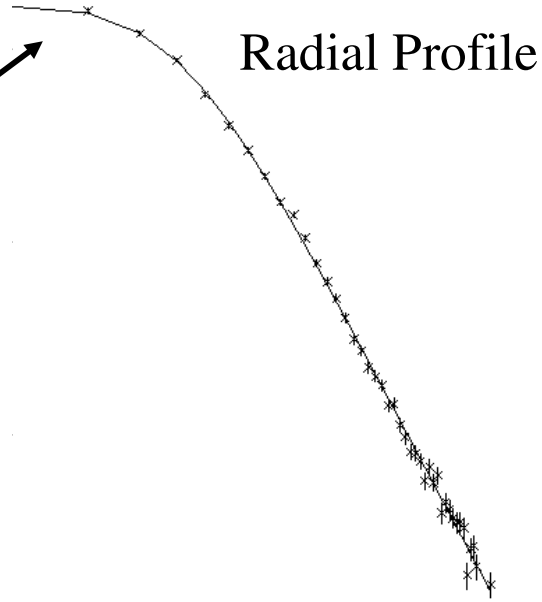
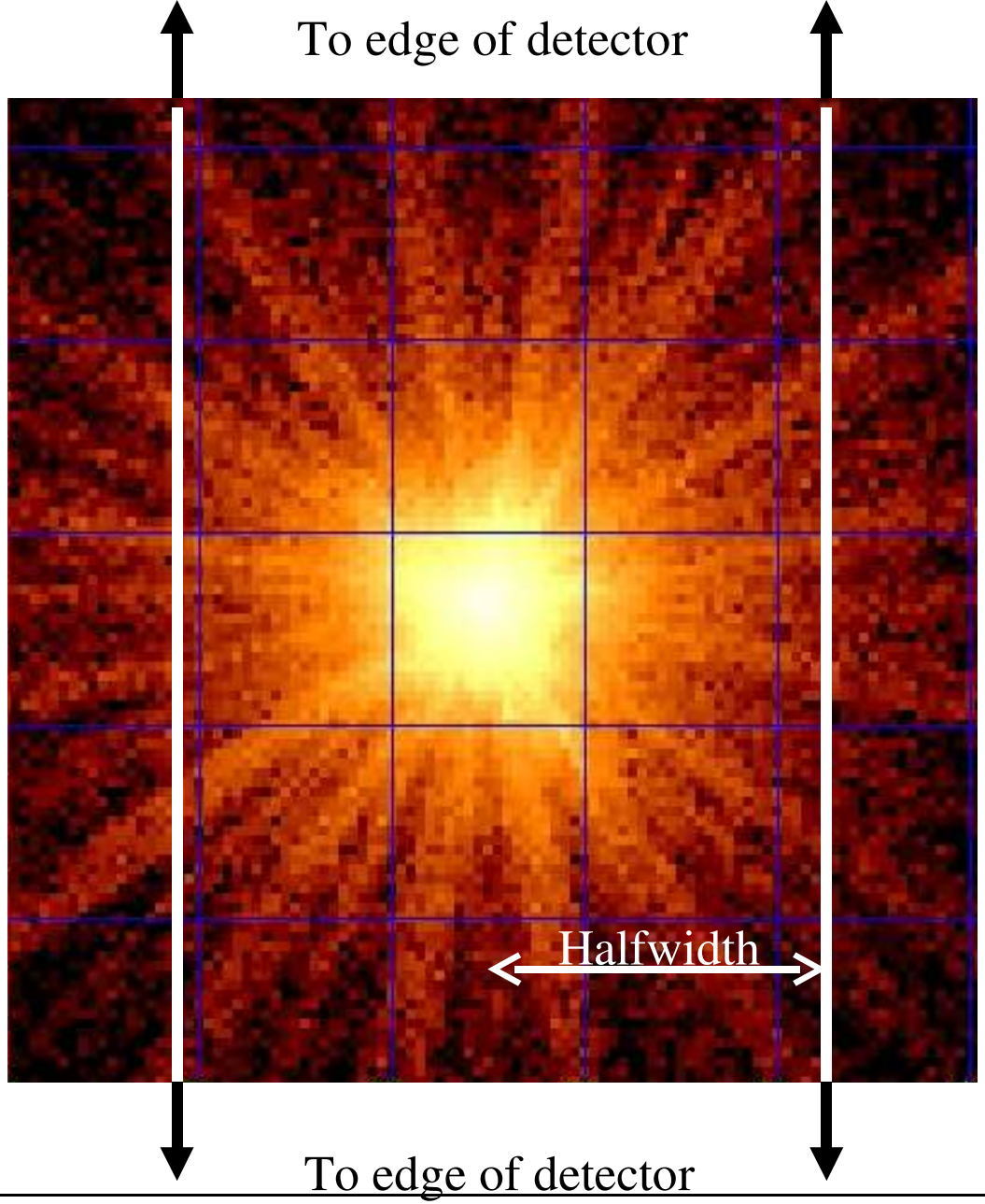
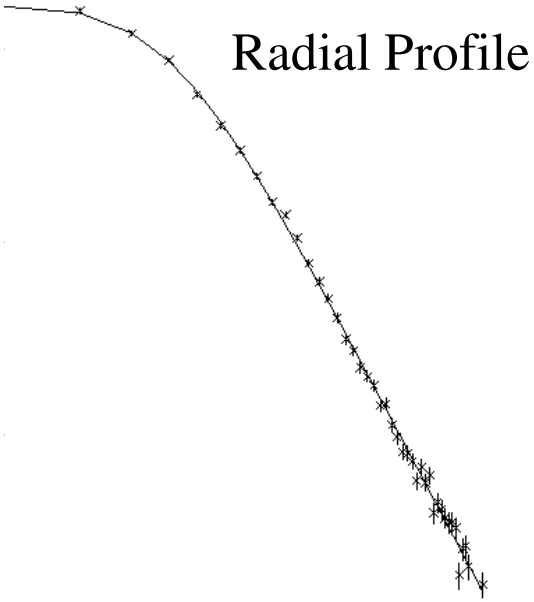




Imaging mode:

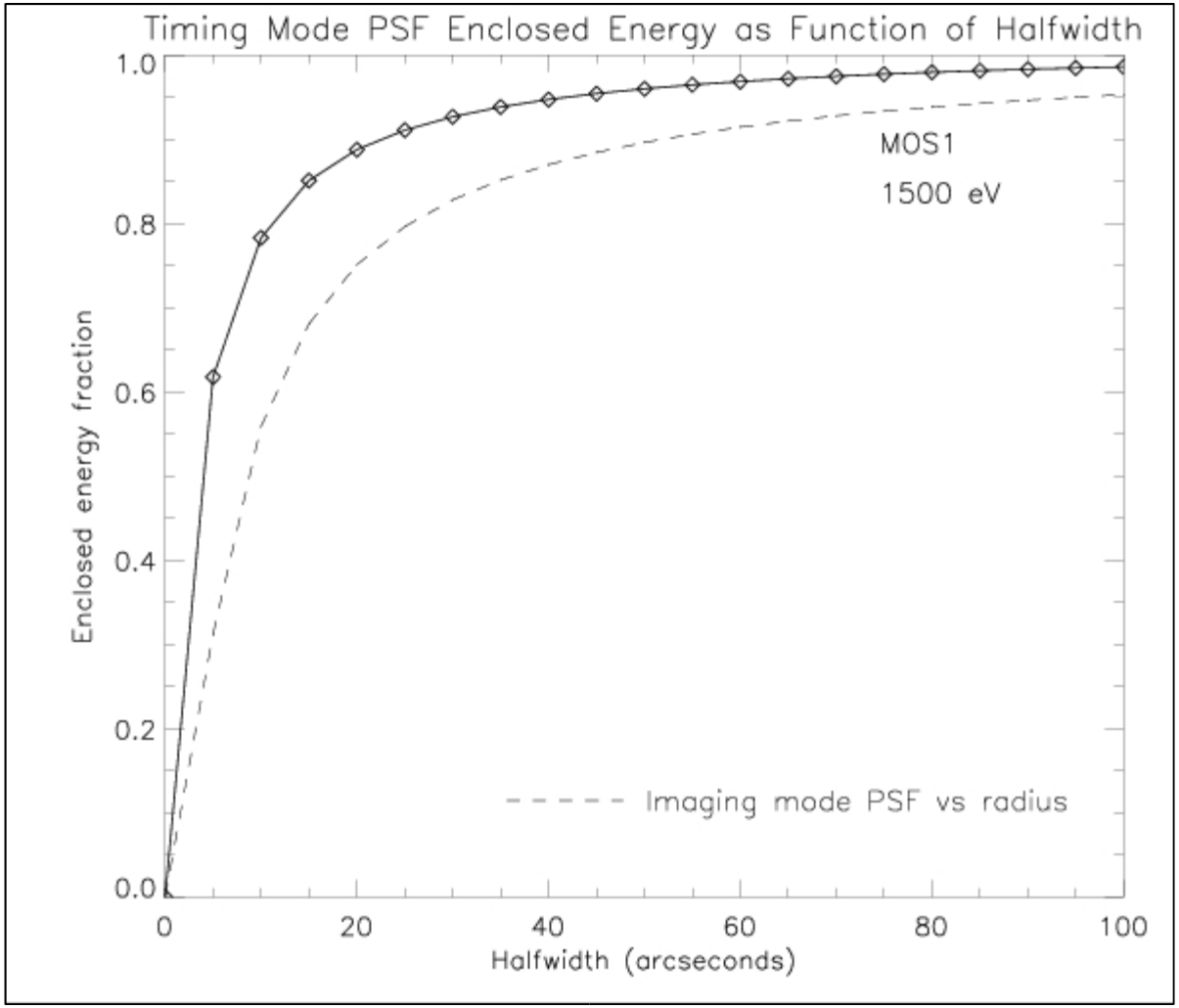
Enclosed energy obtained by integrating surface brightness within circle





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)