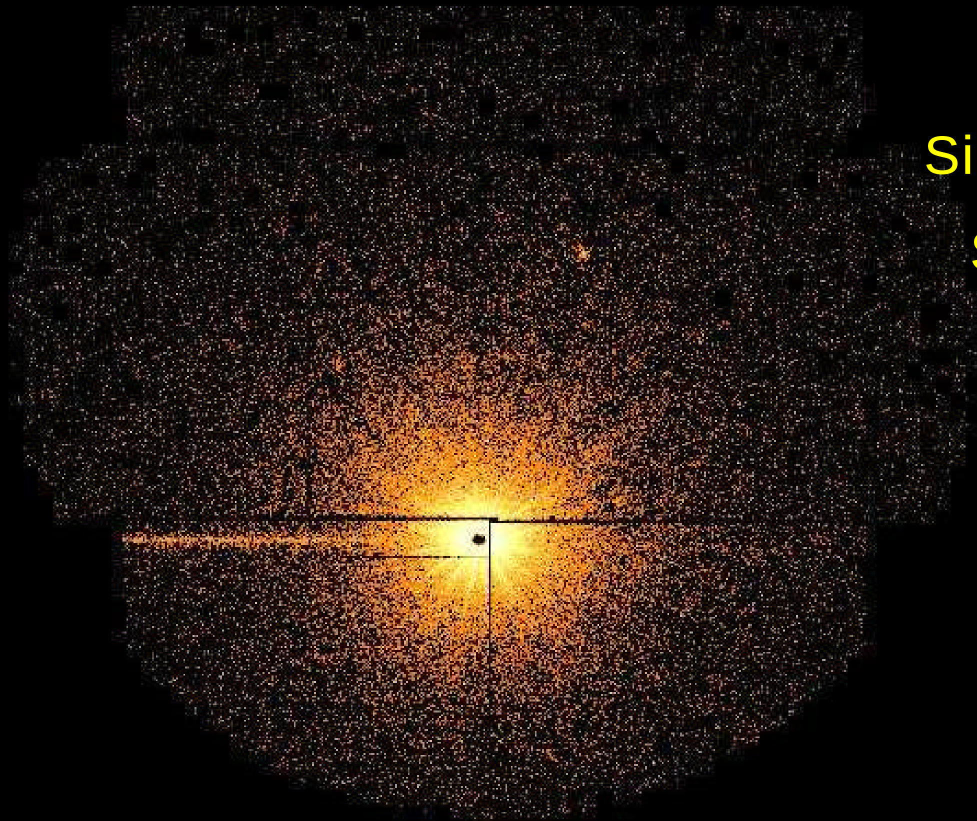
PSF in-flight calibration

for MOS 1 and MOS 2 cameras

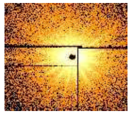


Simona Ghizzardi

Silvano Molendi

OVERVIEW

- The data set
- The analysis procedure
  - Building the radial profile
  - A model for the PSF
  - Fitting the radial profile
- Results



THE DATA SET

ENERGY RANGES:

0.3 keV	[200-400] eV
0.6 keV	[400-800] eV
1.0 keV	[800-1200] eV
1.8 keV	[1200-2400] eV
3.7 keV	[2400-5000] eV
6.5 keV	[5000-8000] eV
10.0 keV	[8000-12000] eV

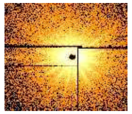
SOURCES:

ON-AXIS

CAPELLA	EXO0748-67	3C273
GX13+1	HR1099	PKS0558
LMC X-3	PKS0312	PSR0540

OFF-AXIS (> ~ 2 arcmin)

HR1099	6.44 (arcmin)
CAPELLA	9.00; 4.48
(Capella)	9.48
GX13+1	5.53; 9.00;9.18;1.92
(GX13+1)	11.89; 2.74; 6.26
3C273	6.31;1.55
PSR0540	9.83
(HCG016)	11.52
(LMC)	11.9; 5.63
OMC2/3	0.34 --> 10.44

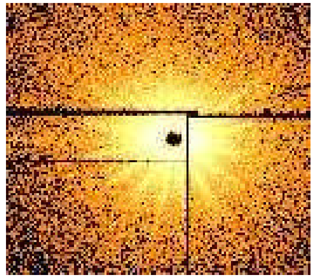


Building the radial profile

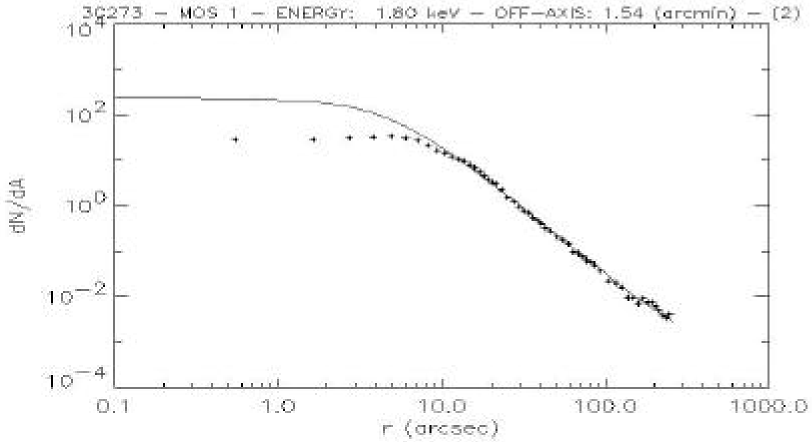
FOR EACH MOS

- **we merged the observations having**
  - **the same source target**
  - **the same pointing position**
  - **different filters and/or operative mode --->**

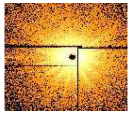
    ---> different pile-up levels



- **The centroid is determined accounting**
- **for the mask of the detector**



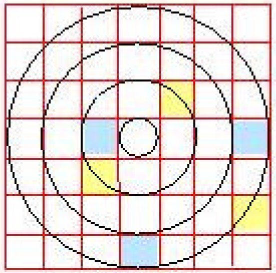
- **For each curve a good fitting range**
- **must be defined (points suffering**
- **for pile-up must be excluded).**



Algorithm for the averaged radial profile

•**Energy selection and pattern (0-12) selection**

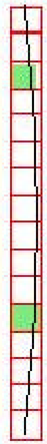
BASIC METHOD



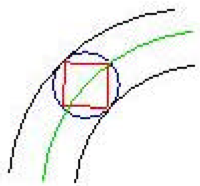
We bin the image (with larger bins at larger radii)

RADIAL PROFILE: dN/dA (the area is not ***2prdr*** because of the mask)

- each (squared) pixel is assigned to the (round) bin to which its CENTER belongs
- for these pixels it works fairly
- these pixels belong to two different bins in comparable fractions
- the effect is less important at larger radii



ADDITIONAL RECIPE ADDED TO THE BASIC PROCEDURE



We enclose each pixel in a circle.

If the circle is **fully** enclosed in the bin then the pixel is too.

If the circle is **partly** enclosed in another bin, the pixel **may** belong to two bins: **we divide such pixels in NSUBPIXELS**

A Model for the PSF

- we want an analytical function to describe the PSF
- according to the ground calibration results (FM1)

PSF = KING + GAUSS

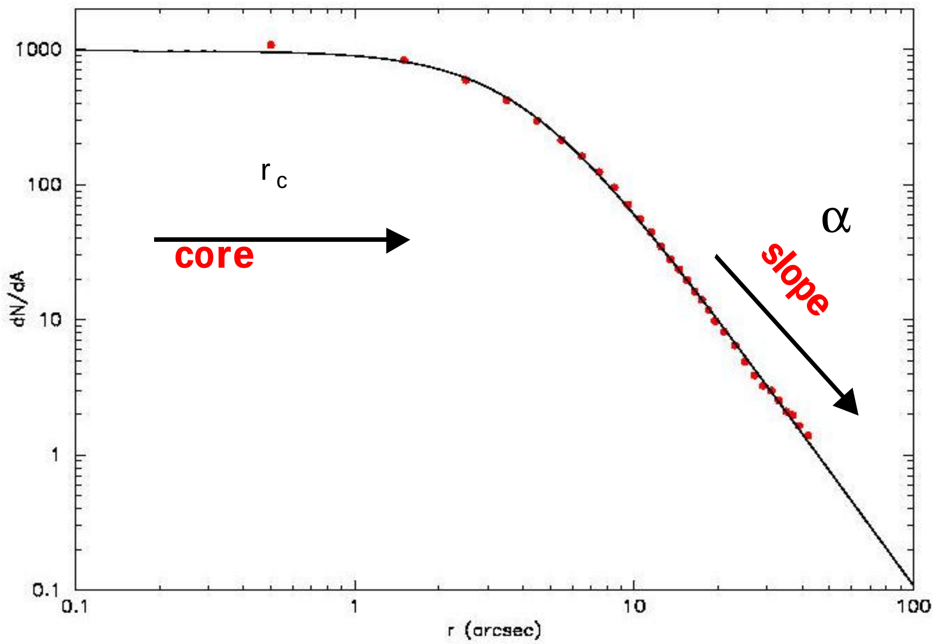
- In orbit PSF

PSF = KING + GAUSS + BKG

BKG in the data is high and Gauss component becomes negligible. Fitting is Gauss parameters-insensitive

- Data often suffer of pile-up. The King slope is well sampled but a large set of data is not useful for the core radius.

King profile



$$King = \frac{A}{\left[1+\left(\frac{r}{r_c}\right)^2\right]^a}$$

Two shape parameters: core radius and slope.

IT CAN BE INTEGRATED ANALYTICALLY IN rdr!!!

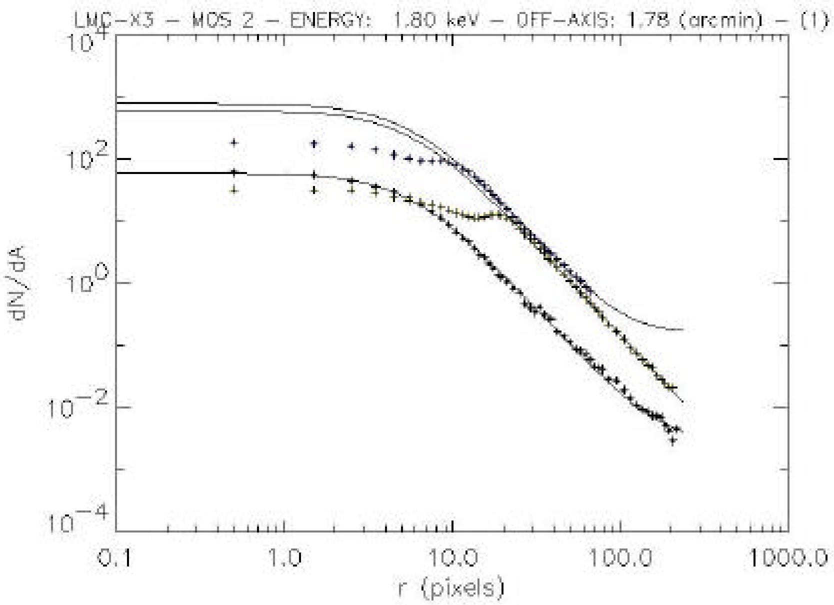
Fitting the radial profiles

In order to enhance the statistics, we fit simultaneously the different curves with different pile-up levels

PSF = King + BKG

α e r_c are the same for the different curves

BKG and the normalization are different for each curve



for each energy and off-axis angle we derive α and r_c.

FOR FIXED OFF-AXIS

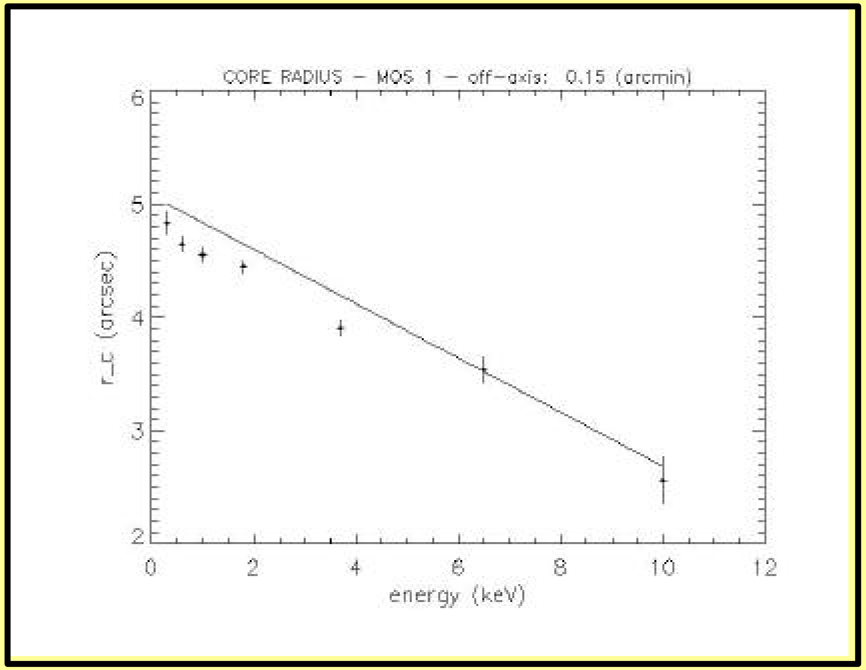
$r_c = r_c(E, \mathbf{J})$

$\mathbf{a} = \mathbf{a}(E, \mathbf{J})$

CORE RADIUS:

tends to decrease when

energy increases (LINEAR).



OFF-AXIS = 0.15 (arcmin)

SLOPE:

the slope is roughly constant with energy

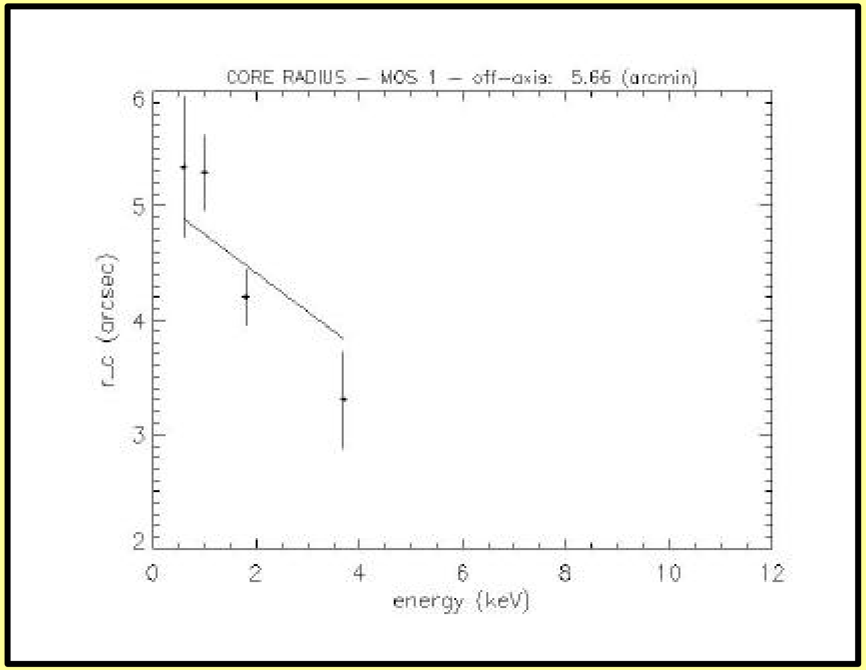
(slightly decreasing - LINEAR).

At higher off-axis angles few data are available.

FOR FIXED OFF-AXIS

$r_c = r_c(E, \vartheta)$

$\alpha = \alpha(E, \vartheta)$



CORE RADIUS:

tends to decrease when energy increases (LINEAR).

OFF-AXIS = 5.66 (arcmin)

SLOPE:

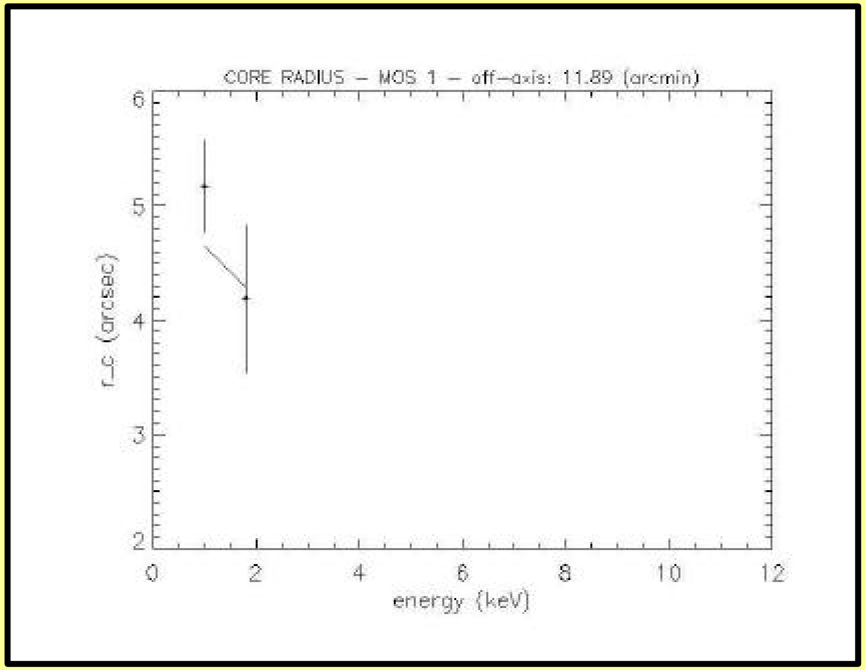
the slope is roughly constant with energy (slightly decreasing - LINEAR).

At higher off-axis angles few data are available.

FOR FIXED OFF-AXIS

$r_c = r_c(E, \mathbf{J})$

$\mathbf{a} = \mathbf{a}(E, \mathbf{J})$



OFF-AXIS = 11.89 (arcmin)

CORE RADIUS:

tends to decrease when

energy increases (LINEAR).

SLOPE:

the slope is roughly constant with energy

(slightly decreasing - LINEAR).

At higher off-axis angles few data are available.

FOR FIXED OFF-AXIS

$r_c = r_c(E, \mathbf{J})$

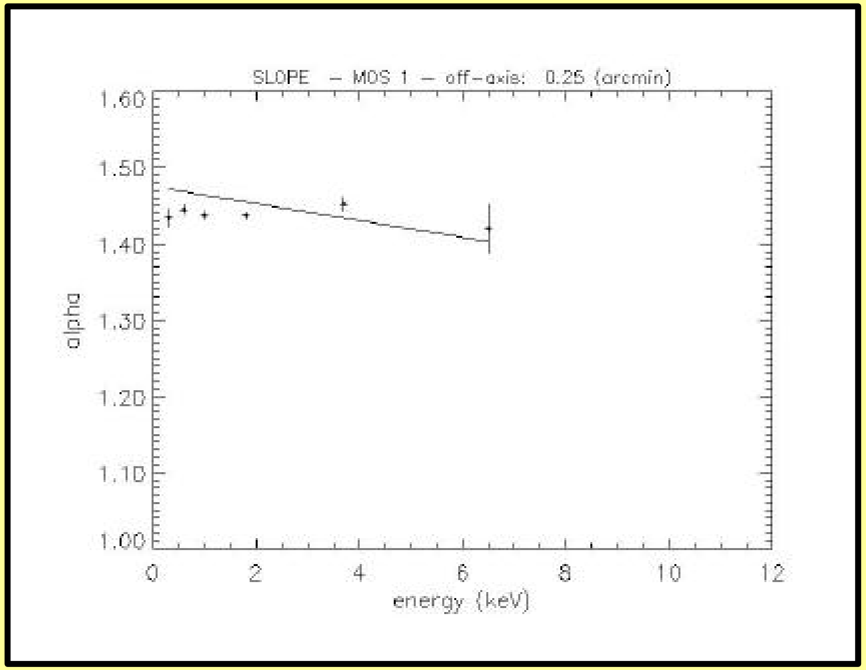
$\mathbf{a} = \mathbf{a}(E, \mathbf{J})$

CORE RADIUS:

tends to decrease when energy increases (LINEAR).

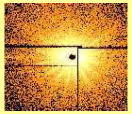
SLOPE:

the slope is roughly constant with energy (slightly decreasing - LINEAR).



OFF-AXIS = 0.25 (arcmin)

At higher off-axis angles few data are available.



FOR FIXED OFF-AXIS

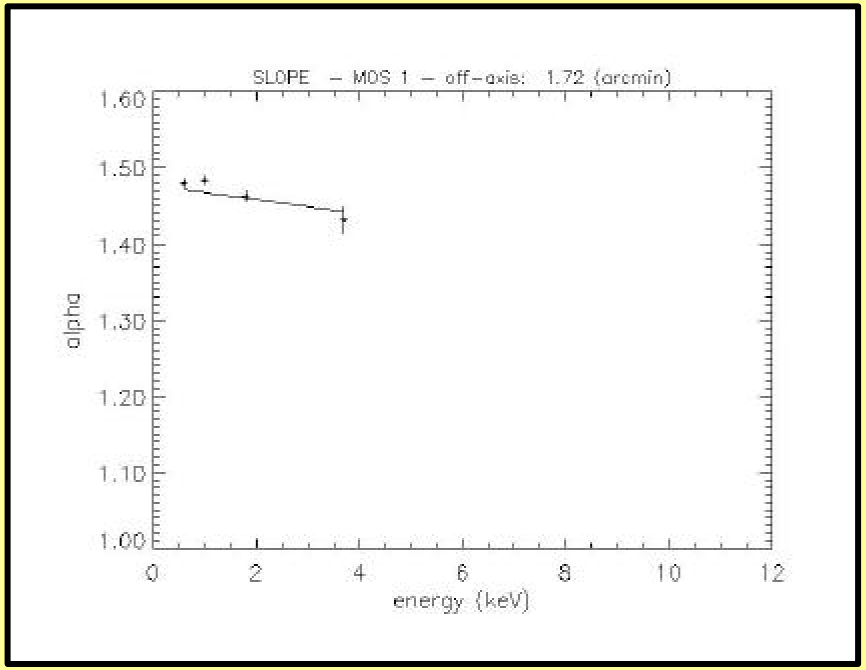
$r_c = r_c(E, \mathbf{J})$

$\mathbf{a} = \mathbf{a}(E, \mathbf{J})$

CORE RADIUS:

tends to decrease when

energy increases (LINEAR).



OFF-AXIS = 1.72 (arcmin)

SLOPE:

the slope is roughly constant with energy

(slightly decreasing - LINEAR).

At higher off-axis angles few data are available.

FOR FIXED OFF-AXIS

$r_c = r_c(E, J)$

$a = a(E, J)$

CORE RADIUS:

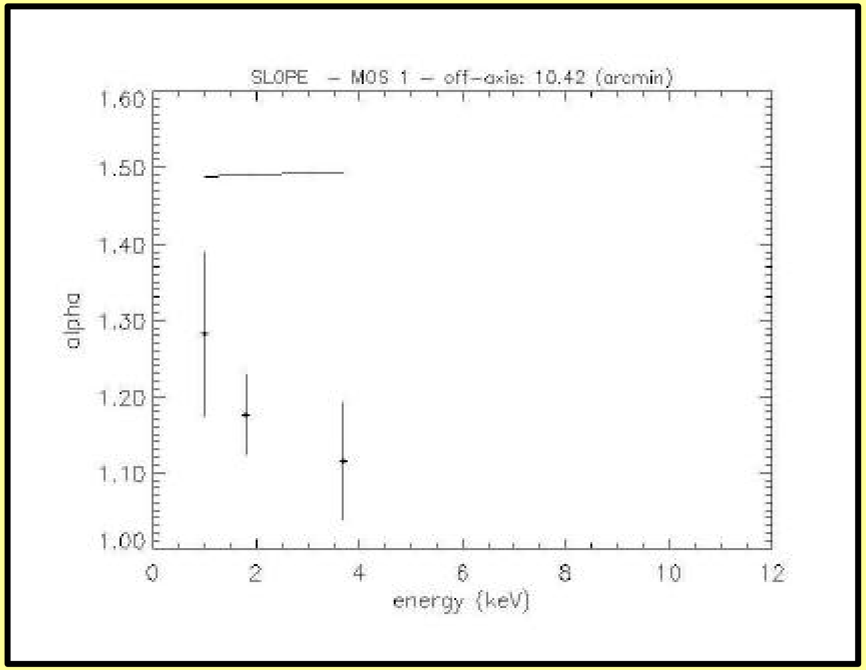
tends to decrease when

energy increases (LINEAR).

SLOPE:

the slope is roughly constant with energy

(slightly decreasing - LINEAR).



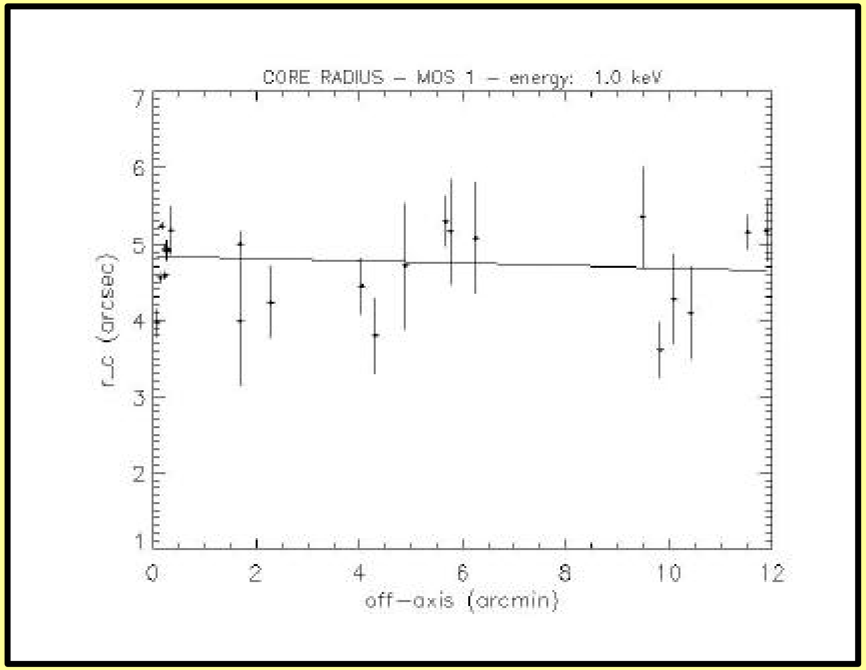
OFF-AXIS = 10.42 (arcmin)

At higher off-axis angles few data are available.

FOR FIXED ENERGY

$r_c = r_c(E, J)$

a = **a**(E, **J**)



ENERGY = 1.0 keV

CORE RADIUS:

is roughly constant

with off-axis angle (LINEAR).

SLOPE:

is roughly constant

with off-axis angle (LINEAR).

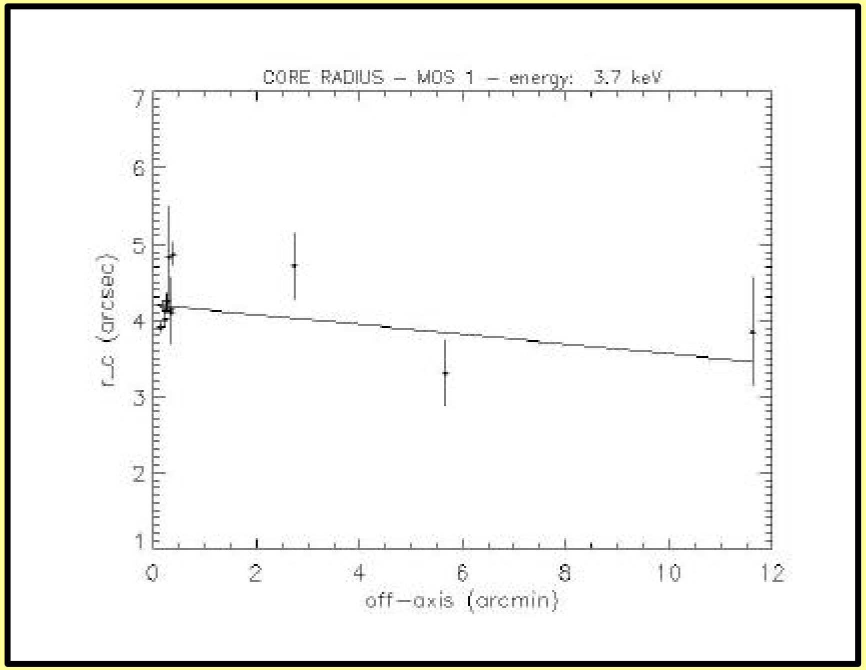
At higher off-axis angles few data are available.

At higher energies few data are available.

FOR FIXED ENERGY

$r_c = r_c(E, \mathbf{J})$

$\mathbf{a} = \mathbf{a}(E, \mathbf{J})$



ENERGY = 3.7 keV

CORE RADIUS:

is roughly constant

with off-axis angle (LINEAR).

SLOPE:

is roughly constant

with off-axis angle (LINEAR).

At higher off-axis angles few data are available.

At higher energies few data are available.

FOR FIXED ENERGY

$r_c = r_c(E, J)$

$a = a(E, J)$

CORE RADIUS:

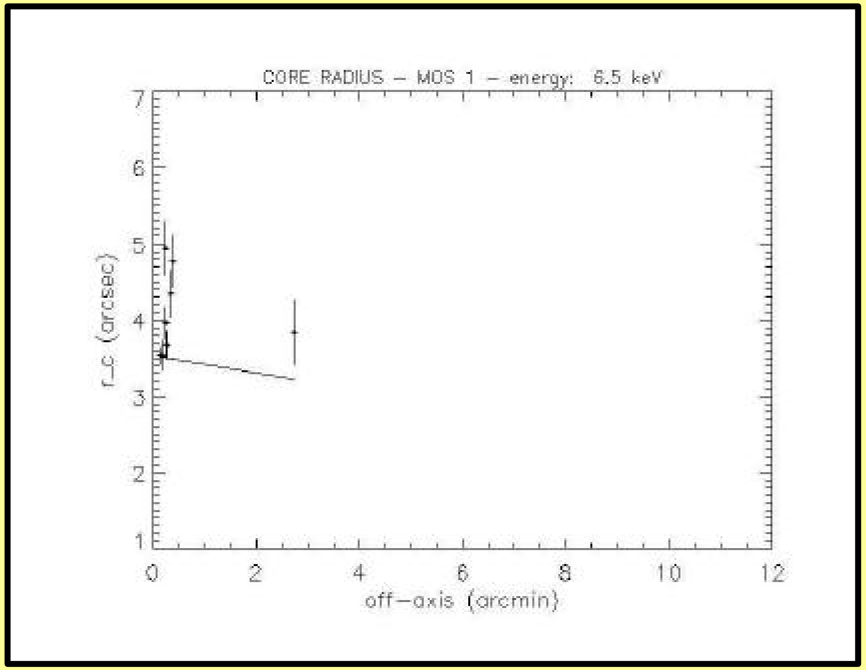
is roughly constant

with off-axis angle (LINEAR).

SLOPE:

is roughly constant

with off-axis angle (LINEAR).



ENERGY = 6.5 keV

At higher off-axis angles few data are available.

At higher energies few data are available.

FOR FIXED ENERGY

$r_c = r_c(E, J)$

$a = a(E, J)$

CORE RADIUS:

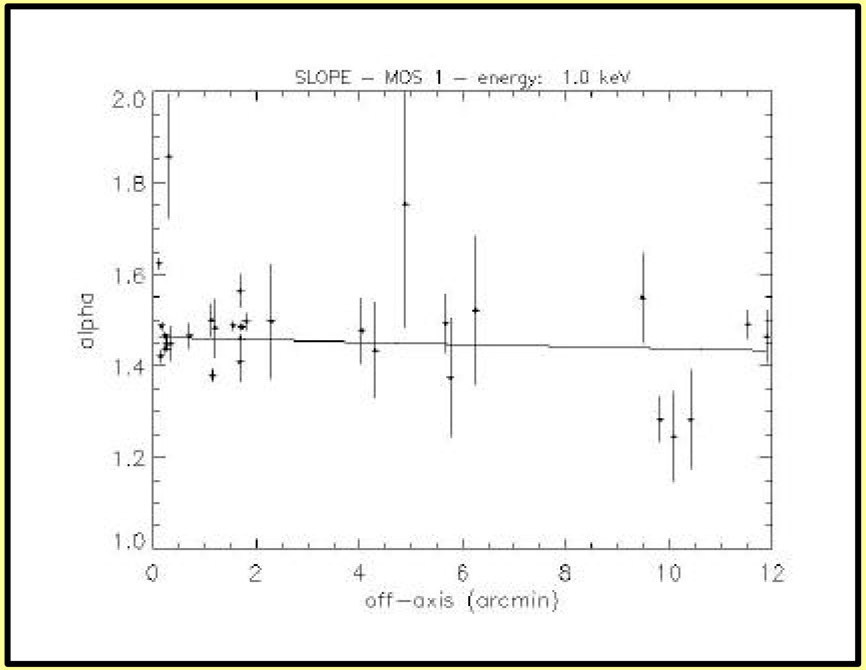
is roughly constant

with off-axis angle (LINEAR).

SLOPE:

is roughly constant

with off-axis angle (LINEAR).



ENERGY = 1.0 keV

At higher off-axis angles few data are available.

At higher energies few data are available.

FOR FIXED ENERGY

$r_c = r_c(E, \theta)$

$\alpha = \alpha(E, \theta)$

CORE RADIUS:

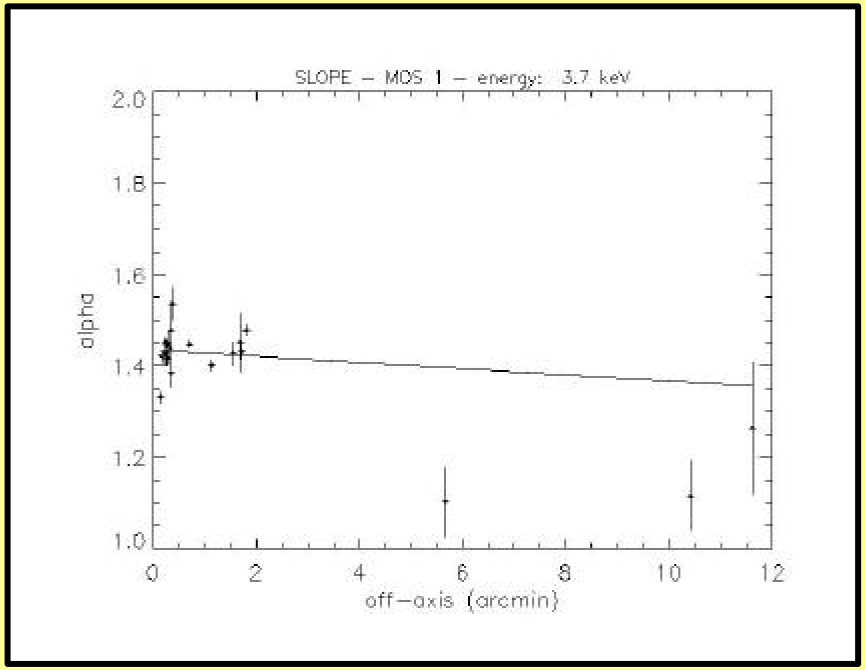
is roughly constant

with off-axis angle (LINEAR).

SLOPE:

is roughly constant

with off-axis angle (LINEAR).



ENERGY = 3.7 keV

At higher off-axis angles few data are available.

At higher energies few data are available.

FOR FIXED ENERGY

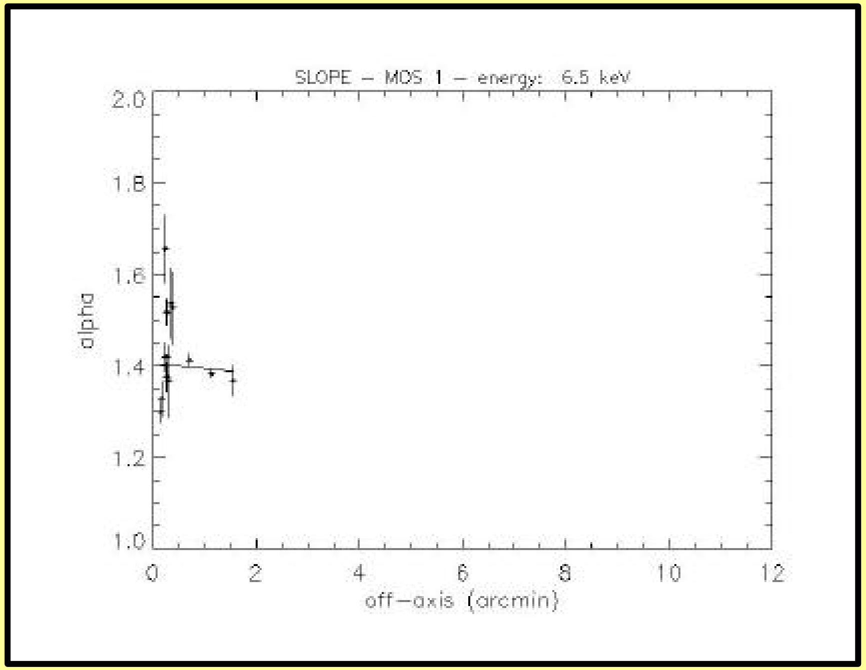
$r_c = r_c(E, \theta)$

$\alpha = \alpha(E, \theta)$

CORE RADIUS:

is roughly constant

with off-axis angle (LINEAR).



ENERGY = 6.5 keV

SLOPE:

is roughly constant

with off-axis angle (LINEAR).

At higher off-axis angles few data are available.

At higher energies few data are available.

FOR FIXED ENERGY

$$r_c = r_c(E, \theta)$$

$$\alpha = \alpha(E, \theta)$$

CORE RADIUS:

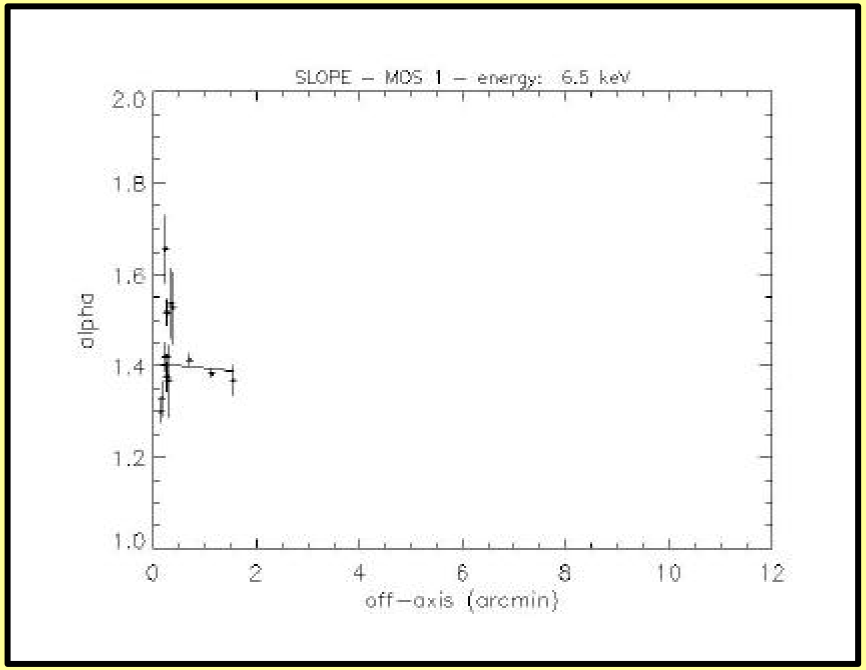
is roughly constant

with off-axis angle (LINEAR).

SLOPE:

is roughly constant

with off-axis angle (LINEAR).



ENERGY = 6.5 keV

At higher off-axis angles few data are available.

At higher energies few data are available.

No data for high ENERGIES AND OFF-AXIS ANGLES.

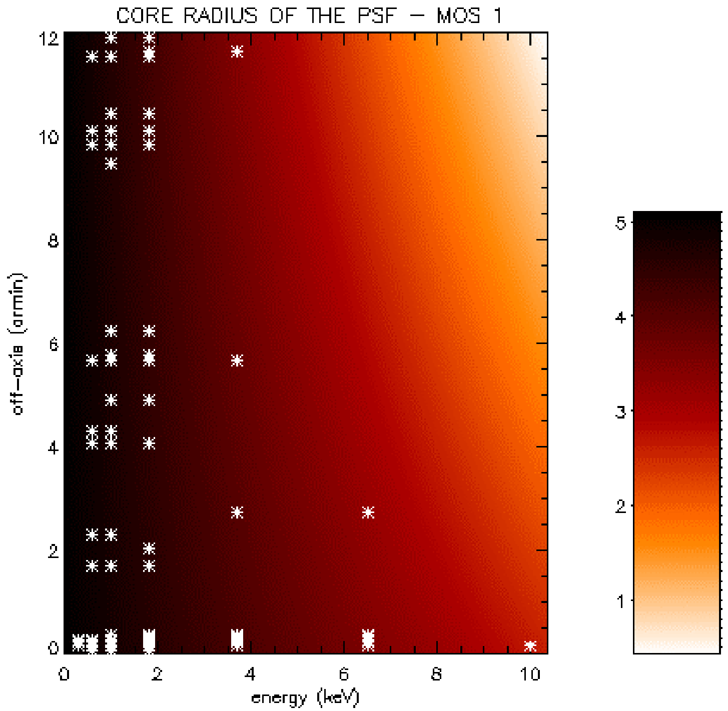
No calibration is possible for these values.

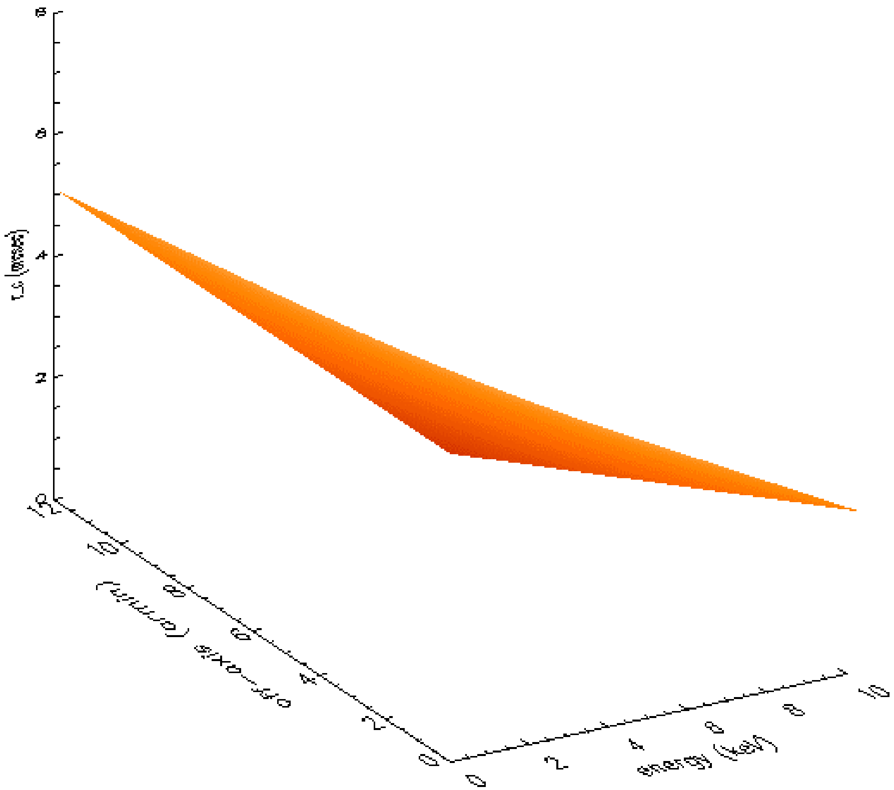
2 DIMENSIONAL FIT

$$r_c = a + b \cdot E + c \cdot \mathbf{J} + d \cdot E \cdot \mathbf{J}$$

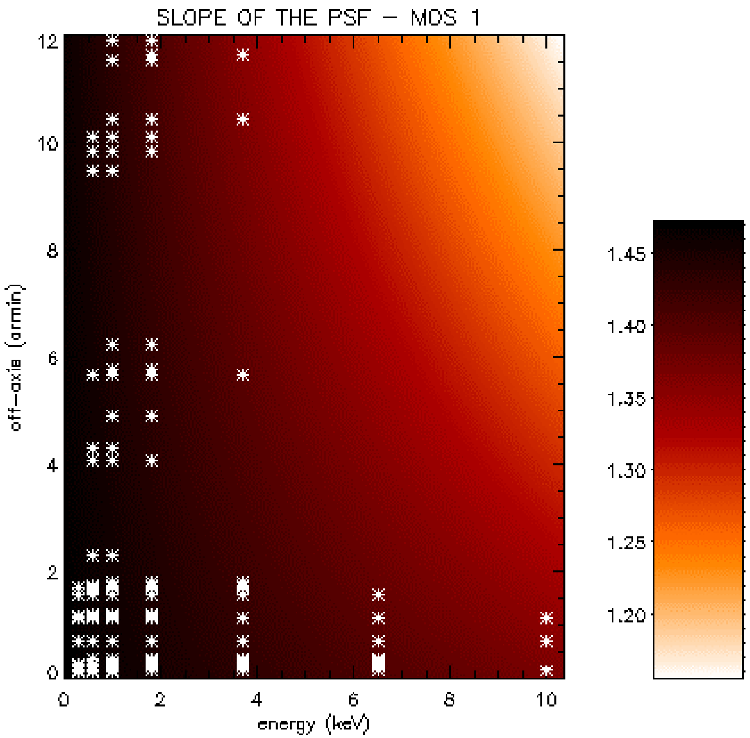
$$\mathbf{a} = x + y \cdot E + z \cdot \mathbf{J} + w \cdot E \cdot \mathbf{J}$$

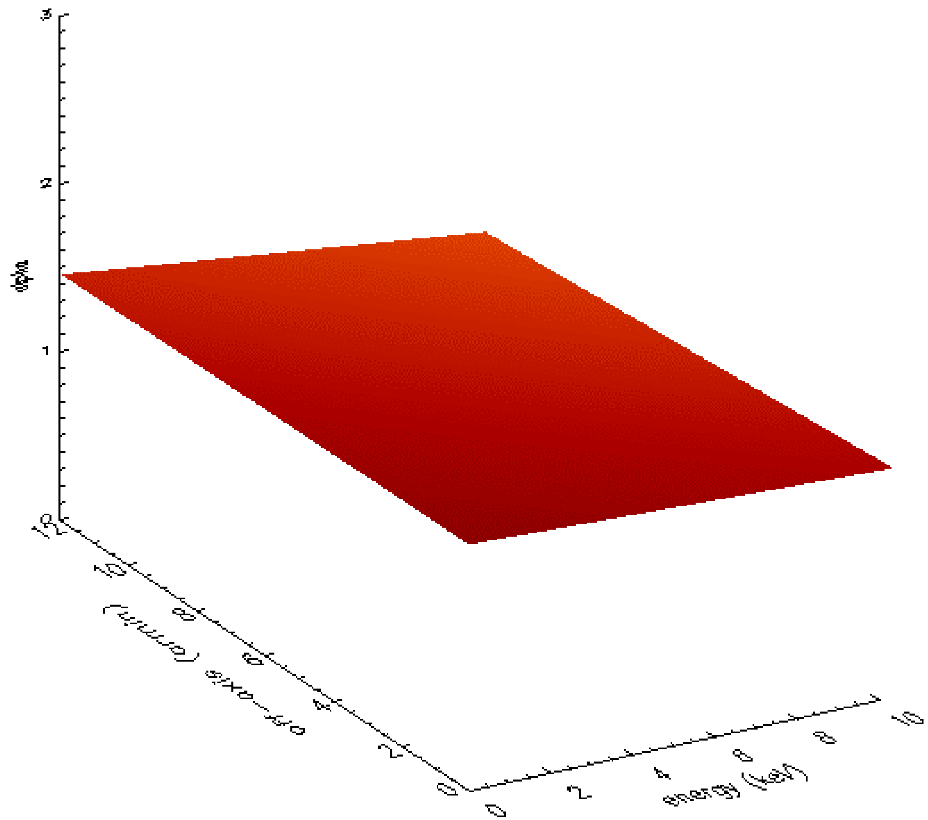
King Core Radius for MOS 1





King Slope for MOS 1





2 DIMENSIONAL FIT

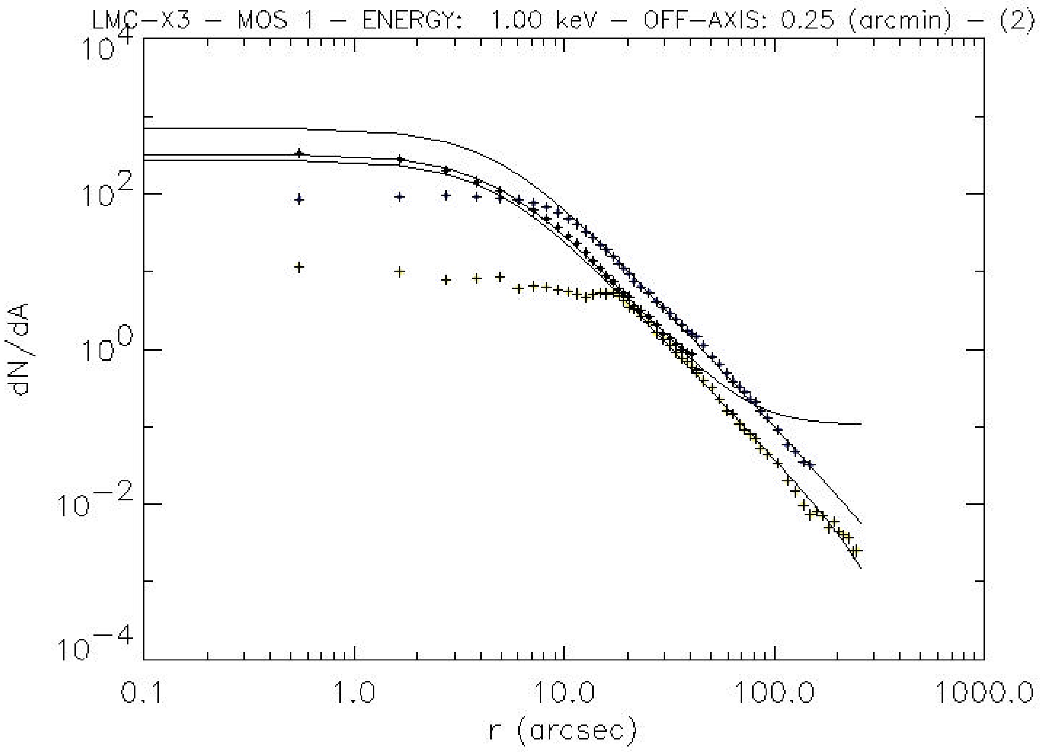
$$r_c = a + b \cdot E + c \cdot J + d \cdot E \cdot J$$

$$\mathbf{a} = x + y \cdot E + z \cdot J + w \cdot E \cdot J$$

	MOS 1			
r_c	$a = 5.074 \pm 0.001$	$b = -0.236 \pm 0.001$	$c = 0.002 \pm 0.001$	$d = -0.0150 \pm 0.0006$
α	$x = 1.472 \pm 0.003$	$y = -0.010 \pm 0.001$	$z = -0.001 \pm 0.002$	$w = -0.0016 \pm 0.0013$
	MOS 2			
r_c	$a = 4.759 \pm 0.015$	$b = -0.203 \pm 0.010$	$c = 0.014 \pm 0.017$	$d = -0.0229 \pm 0.0133$
α	$x = 1.411 \pm 0.001$	$y = -0.005 \pm 0.001$	$z = -0.001 \pm 0.002$	$w = -0.0002 \pm 0.0011$

r_c and α are fixed to the best fit parameters.

The normalization and the background are free parameters.



r_c and α are fixed to the best fit parameters.

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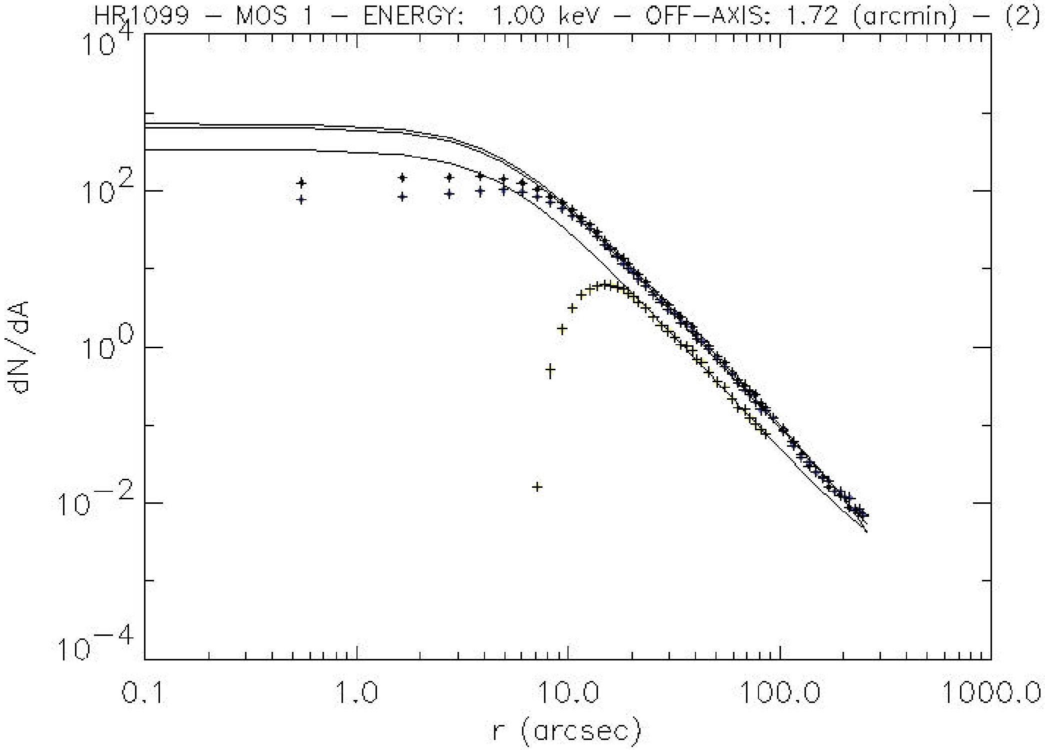
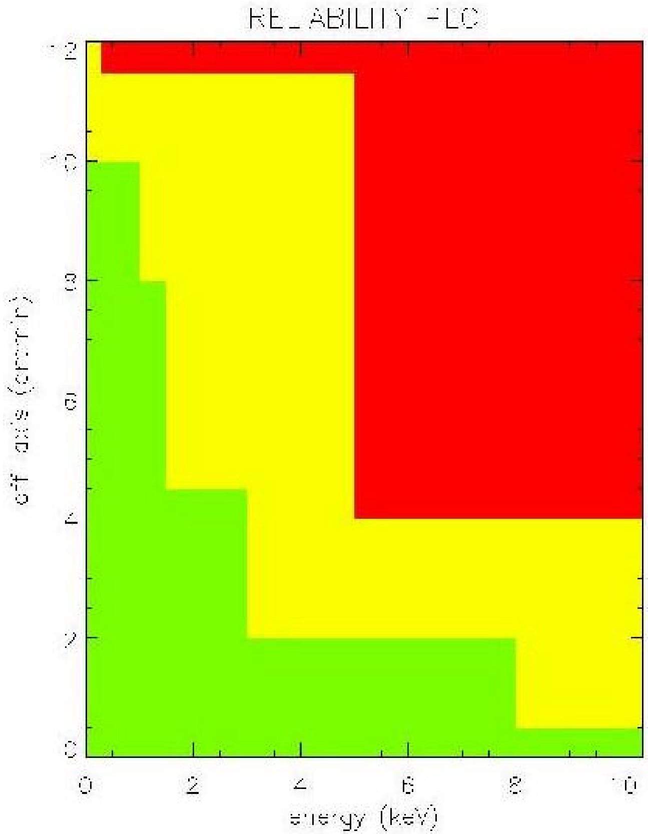


Range of Application



Calibration here is well sampled and the modelization provides a good description of the PSF.

Few scattered data with large errors are available here. The modeled PSF must be used with caution.

No data are available here. No calibration is possible in this region.

DON'T USE THE MODEL FOR THESE VALUES.

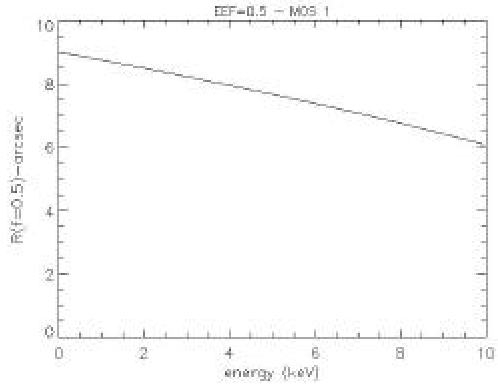
ENCIRCLED ENERGY FRACTION

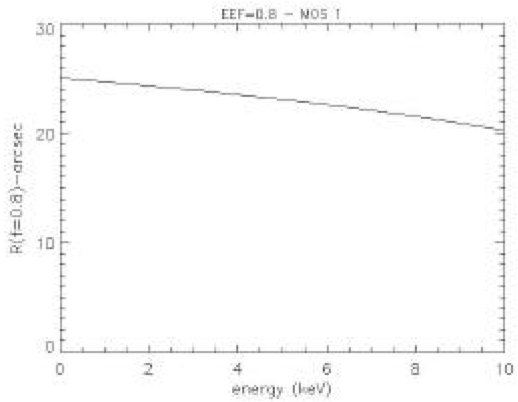
EEF IS ANALYTICAL

Radii enclosing 50% and 80% of the energy

at 1.5 keV, 8 keV, 9 keV for the on-axis PSF.

MOS 1					
R(50%)			R(80%)		
1.5 keV	8 keV	9 keV	1.5 keV	8 keV	9 keV
8.6″	6.7″	6.4″	24.5″	21.5″	20.9″
MOS 2					
R(50%)			R(80%)		
1.5 keV	8 keV	9 keV	1.5 keV	8 keV	9 keV
9.1″	7.0″	6.6″	27.7″	23.1″	22.3″





EEF also for piled-up sources.

SUMMARY

- An analytical model for the PSF and the EEF has been provided
- Using a wide set of data, the best fit parameters are provided as functions of the energy and of the off-axis angle.
- A range of application of the model is defined:
  - At high energies and off-axis angles no calibration is possible.
  - The model must be used with caution at intermediate energies/off-axis angles
- Full detailed report available at

http://www.ifctr.mi.cnr.it/~simona/PSF_inorbitMOS.ps

NEXT PN !