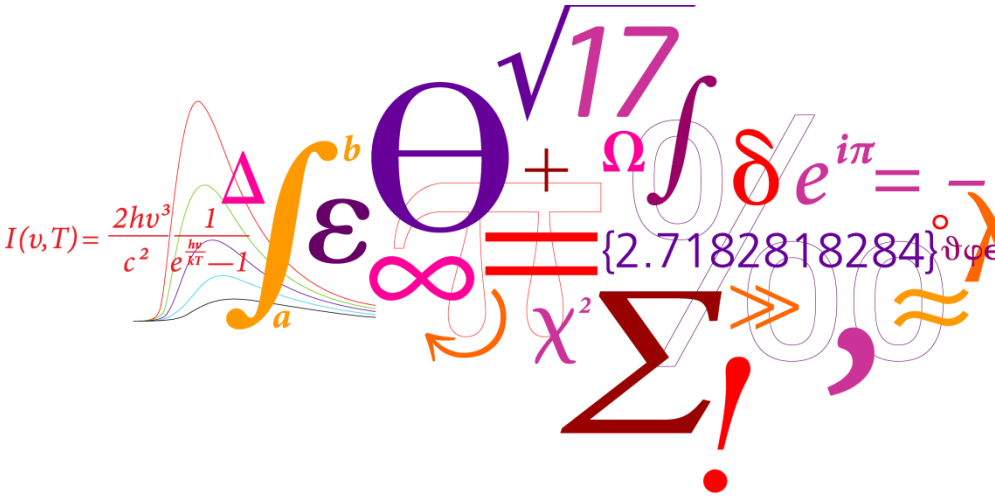
Observing clusters of galaxies with NuSTAR

Niels J. Westergaard

May 14, 2014



DTU Space
National Space Institute

What have we got sofar?

Bullet cluster

Abell 2256

Coma Center (Abell 1656)

Coma Shock

What are the new targets?

Abell 1795?

Ophiuchus ?

Abell 2029 ?

Simulation of a NuSTAR A1795 observation

A 10^5 s observation of Abell 1795, a cooling core cluster of galaxies, has been simulated for a single NuSTAR instrument. The software used is MT_RAYOR and the results are reported here. This work is done in collaboration with Jukka Nevalainen for IACHEC.

The input image and spectrum.

XMM MOS observation + the derived 'mekal' spectrum:

phabs*mekal

nH = 0.0119 cm-2

kT = 4.63 keV

nH(plasma) = 1 cm-3

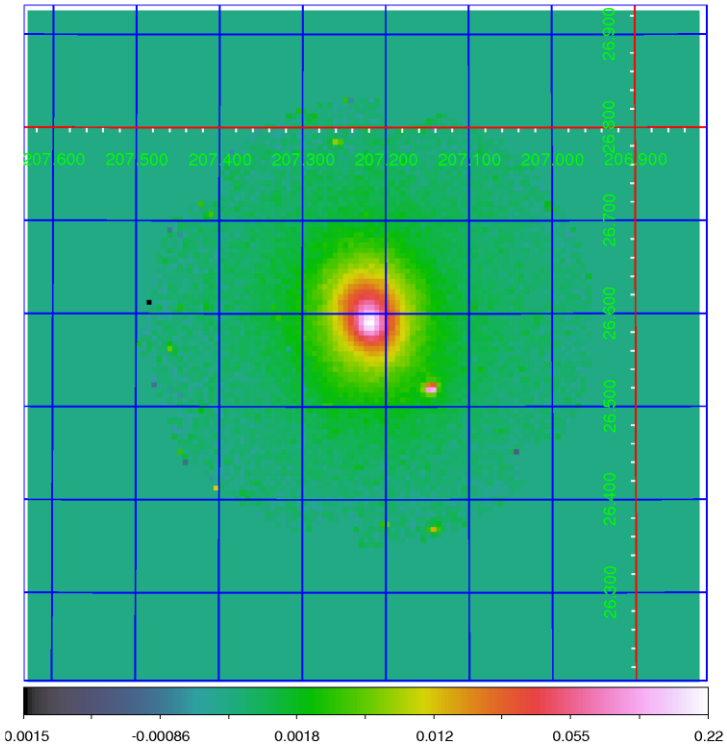
Abun = 0.471

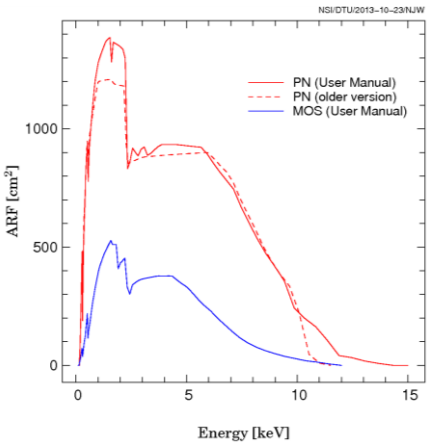
Z = 0.0625

Switch = 0

Norm = 0.0599 (set from image)

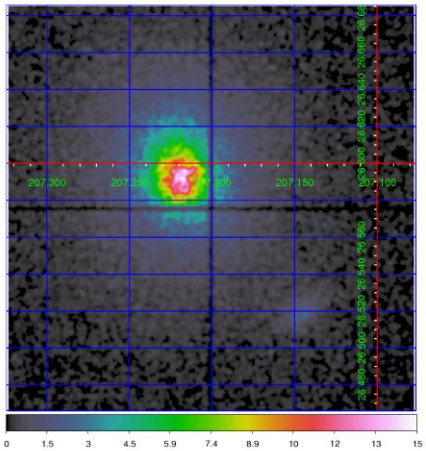
The MOS countrate (in logarithmic color scale to enhance the outer structures) from XMM in 130 x 130 pixels.



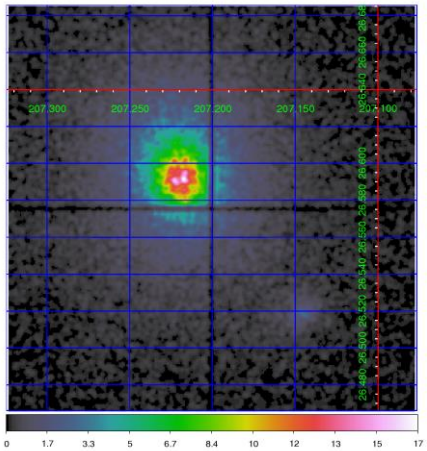


The conversion from XMM MOS counts to spectral normalization is done with the blue ARF shown here.

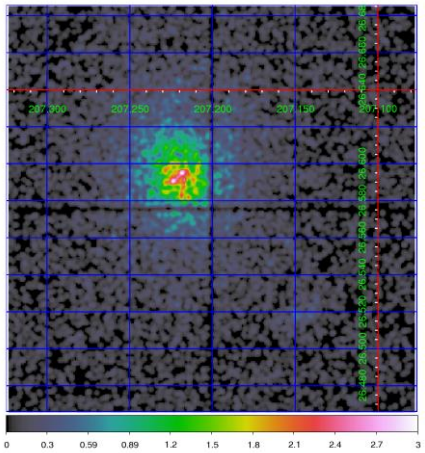
NuSTAR focal plane images in 4 energy bands, exposure is 10^5 s.



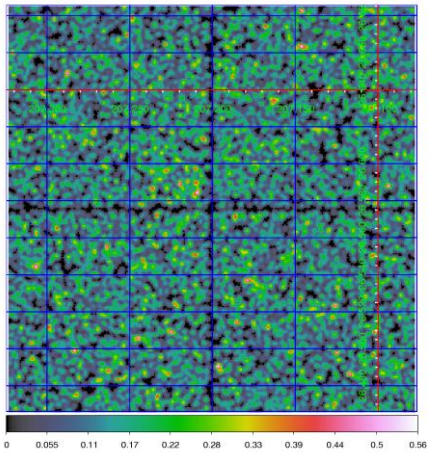
2 – 5 keV



5 – 10 keV



10 – 20 keV



20 – 40 keV

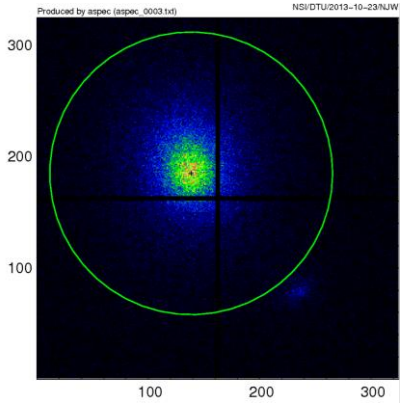
The center of the cluster is offset wrt the detector center to avoid the gap between the chips.

The background is taken to be uniform and otherwise (strength and energy distribution) from the Bullet Cluster observation (see Wik *et al.*, 2013, preprint).

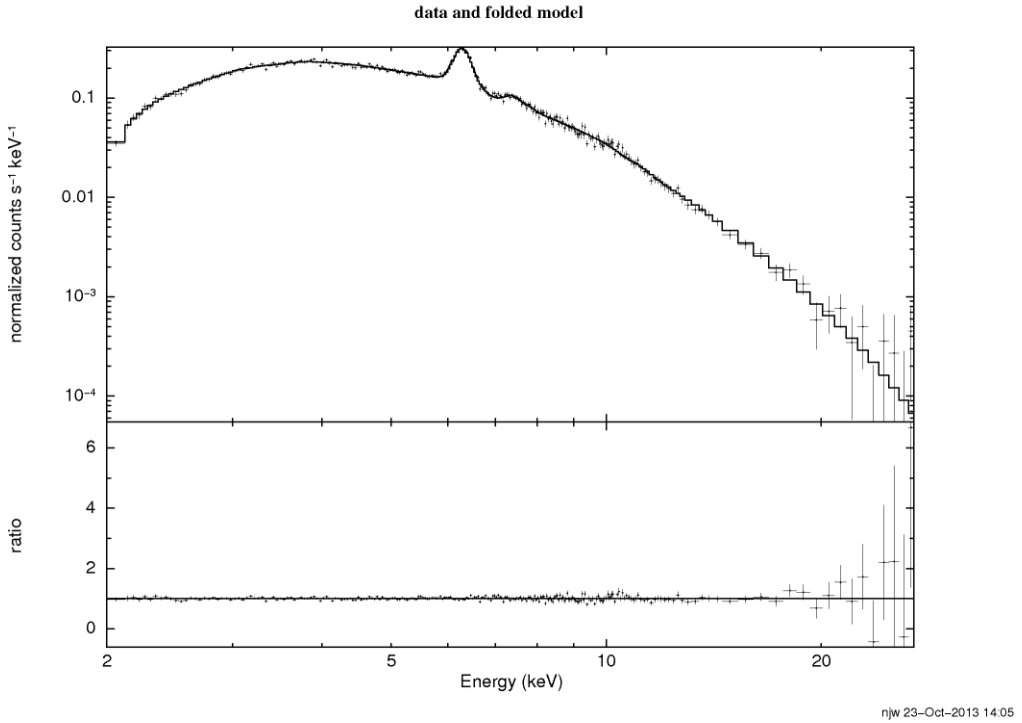
The images here are in pixels of size 2.5” (a fifth of the physical pixels, just like the real observations) and cover the entire detector.

In this simulation the temperature is taken to be uniform although it is known to be increasing with radius from the cluster center (see e.g. Tamura *et al.* 2001, A&A 365, L87).

Extracted spectrum etc.



The extraction region. The background is taken from an independent simulation.



The extracted spectrum and fit. Only temperature and normalization are free parameters.

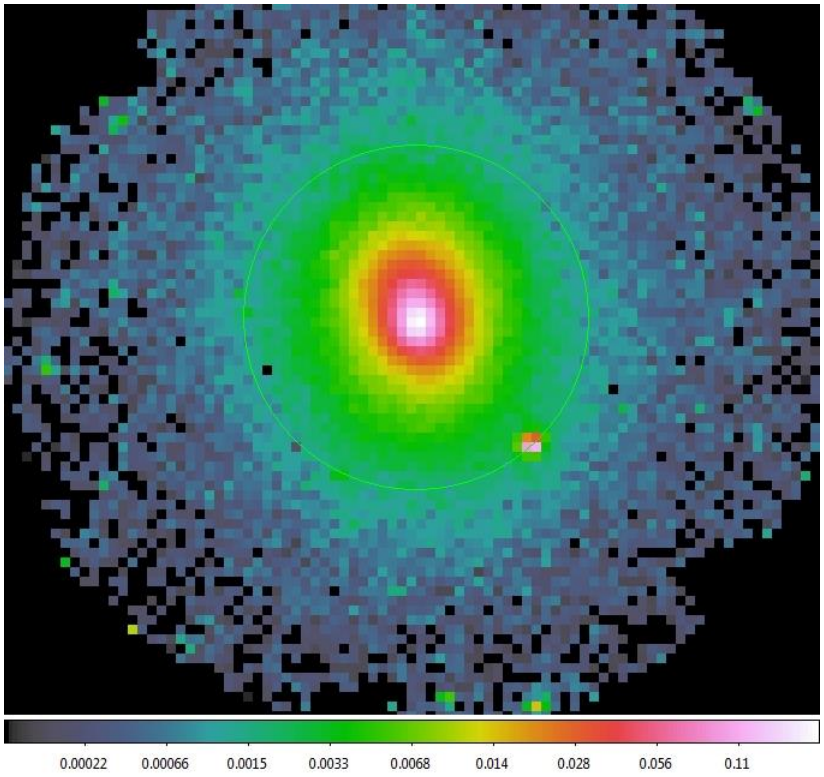
Number of counts (total)	180,000
Number of counts (background)	49,200

Spectral fitting results:

kT = 4.63 +- 0.03 keV

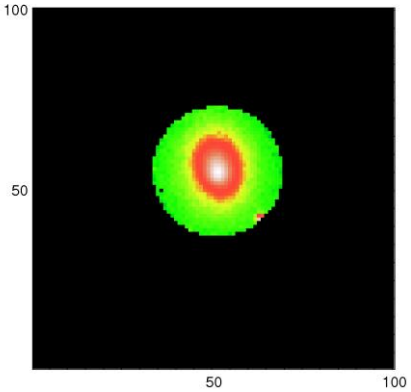
Norm = 0.0612 +- 0.0005

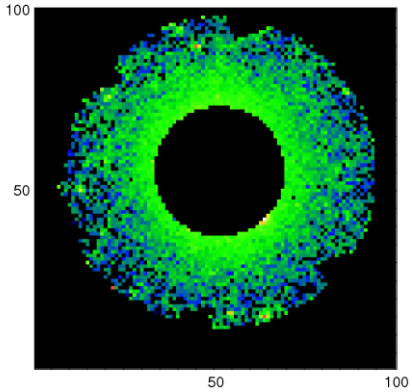
Ghost ray analysis

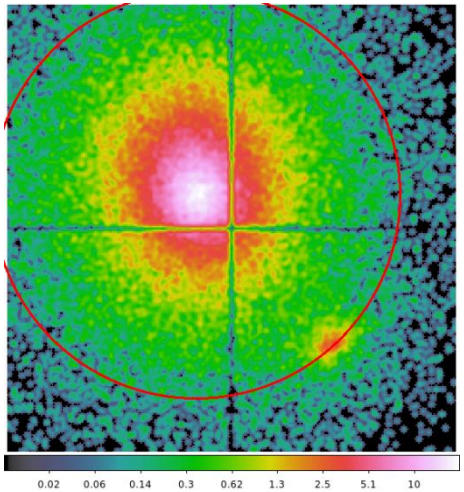


A logarithmic representation of the cluster emission from the MOS1 XMM image with the 6 arcmin radius circle indicated.

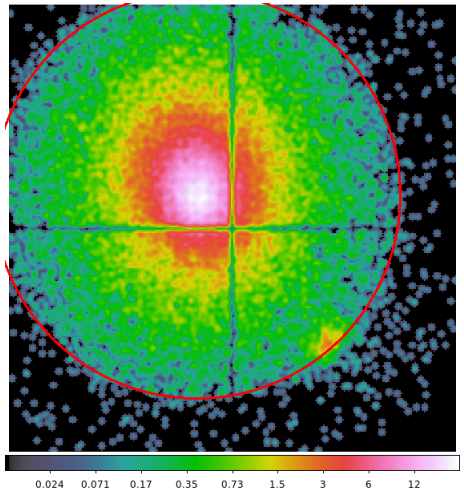
Below: For the ghost ray analysis the image was split up with respect to the 6 arcmin radius.

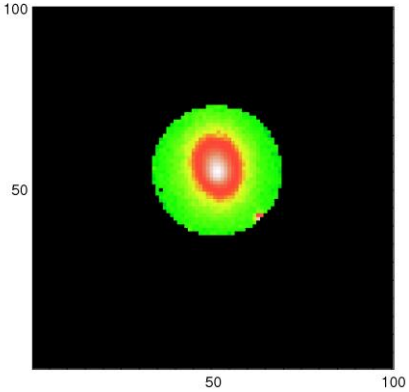


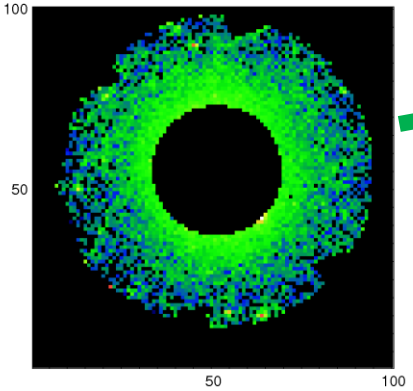




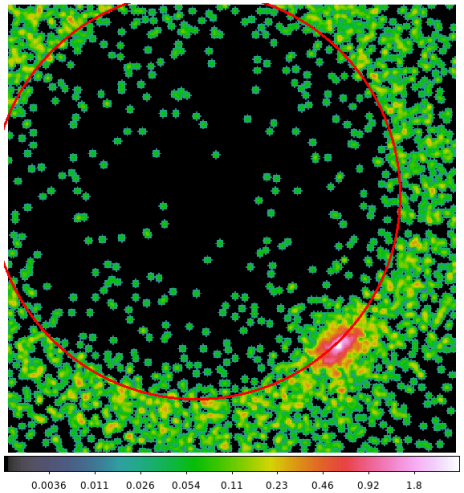
No background has been included in these images

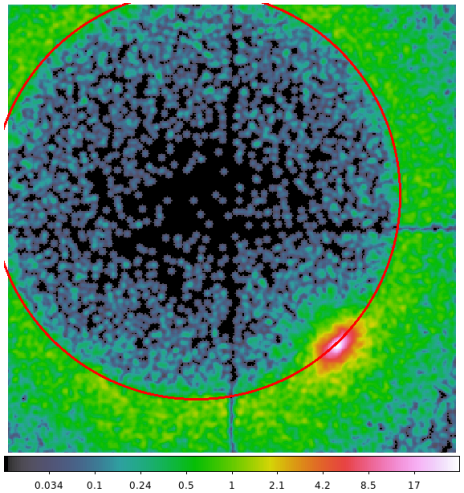






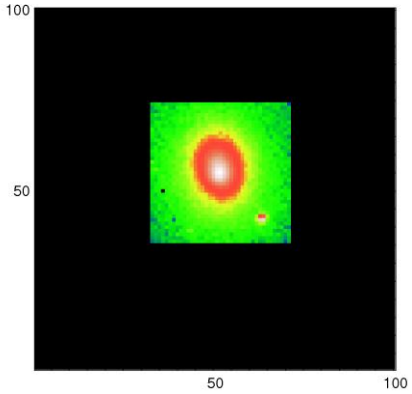
10 x as many photons

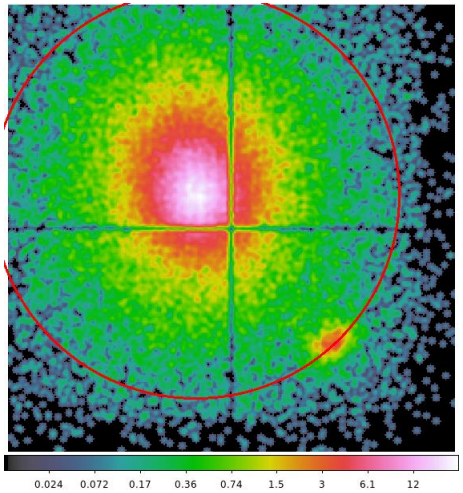


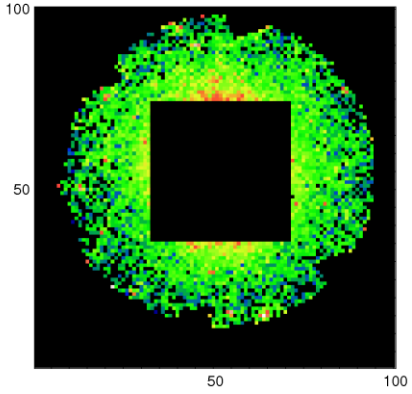


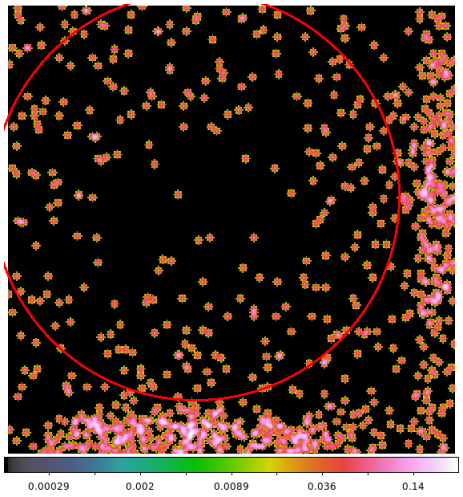
Similarly the 'contamination' from just outside the detector is investigated.

Below: 13 x 13 arcmin square.

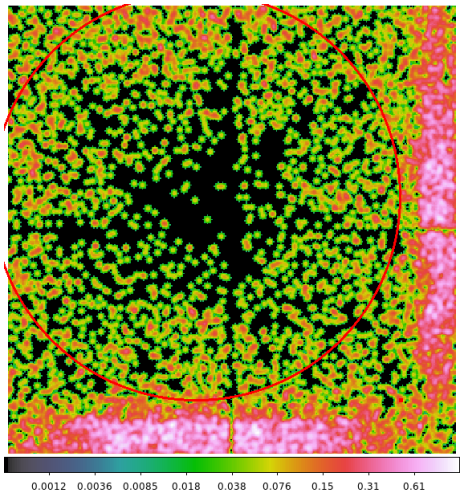


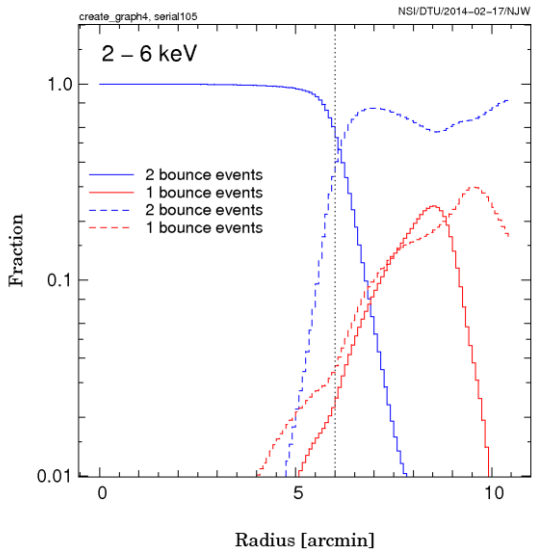


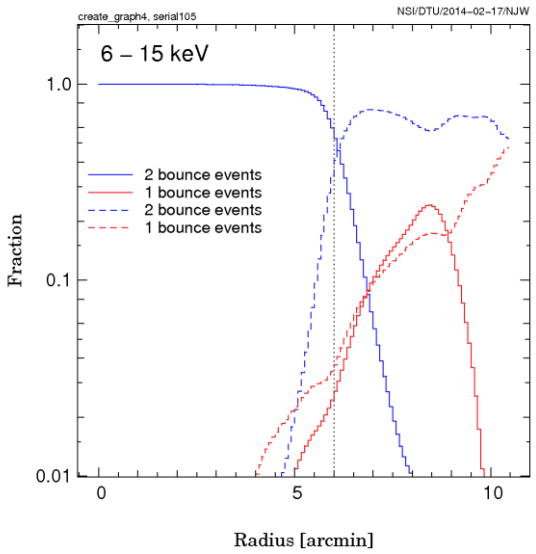


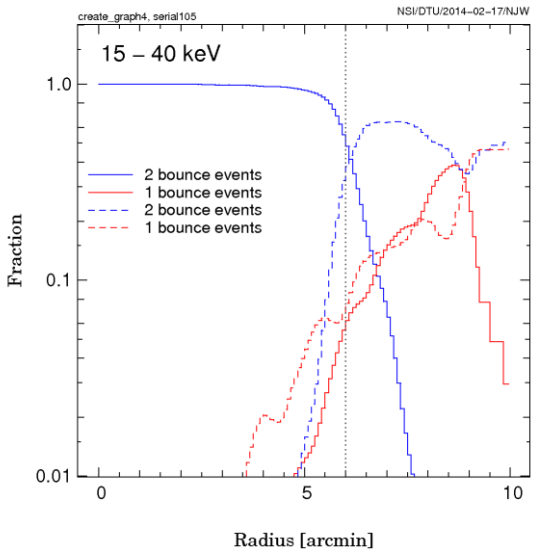


10 x as many photons





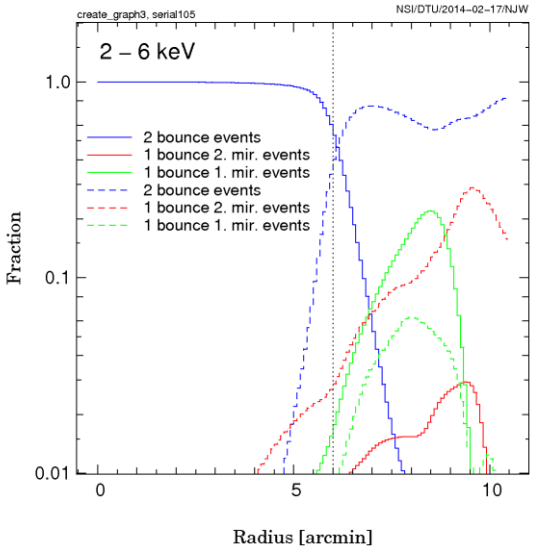


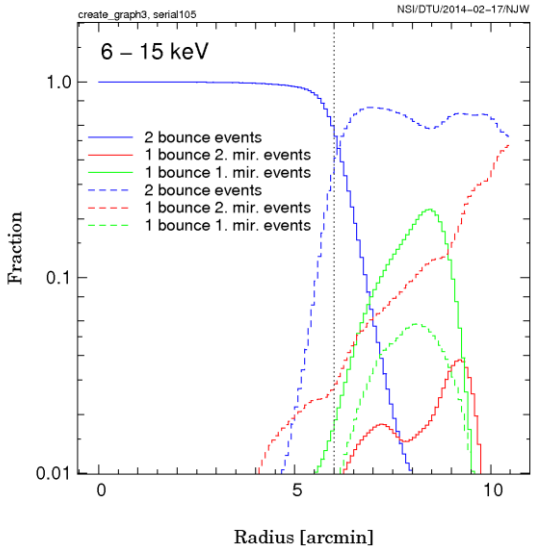


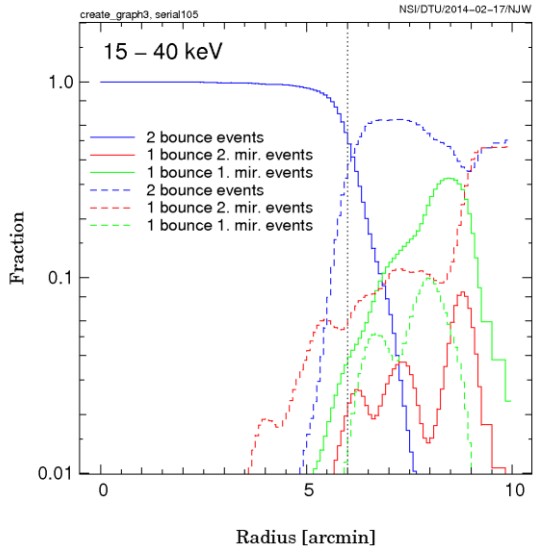
Radial profiles centered on the cluster center have been extracted both from images where all source contributions have an upper radius limit of 6’ (represented by a full curve) and those with a lower limit of 6’ (represented by a dashed curve).

The curves show the fraction of counts from each of the four components. Note the logarithmic scale.

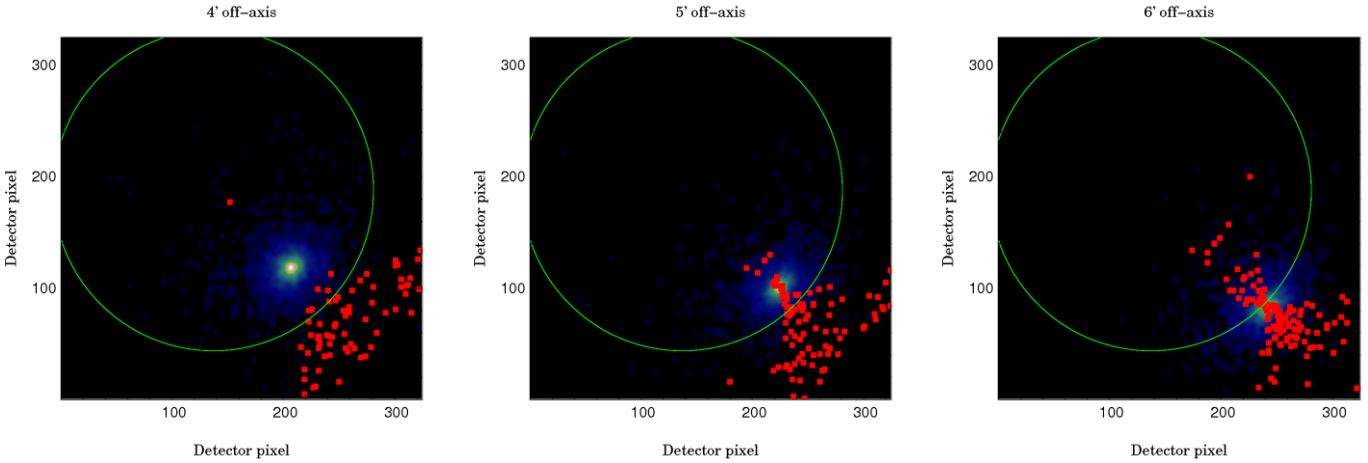
For this cluster the ’contamination’ from the outer regions of the cluster emission is small.

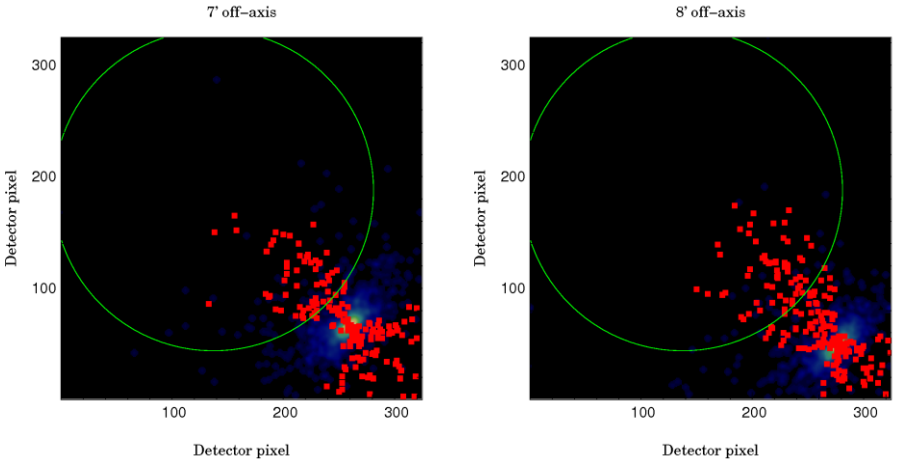






Same as on the previous slide, except that the single bounce events (ghost rays) have been separated whether bouncing on the first, upper mirror, or on the second, lower mirror.

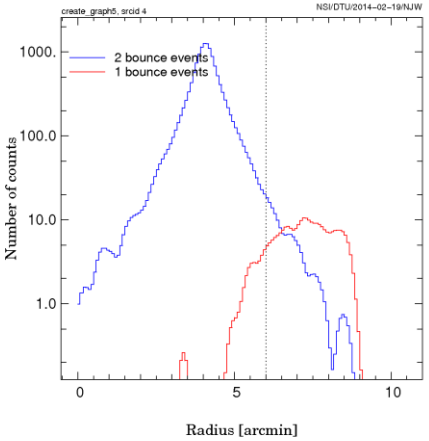


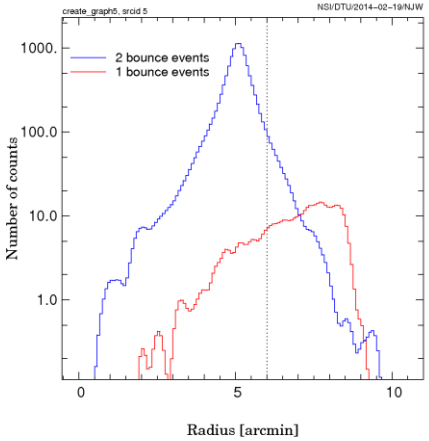


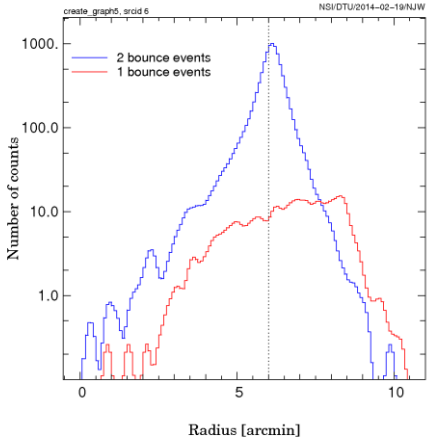
A series of monochromatic (4 keV) point sources placed at increasing off-axis angle.

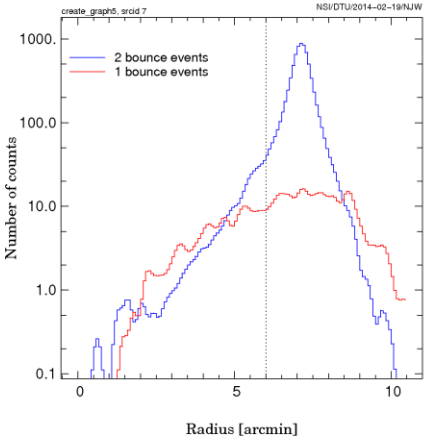
The ghost rays from these fall mainly right outside the 6' circle although with a broader and broader distribution.

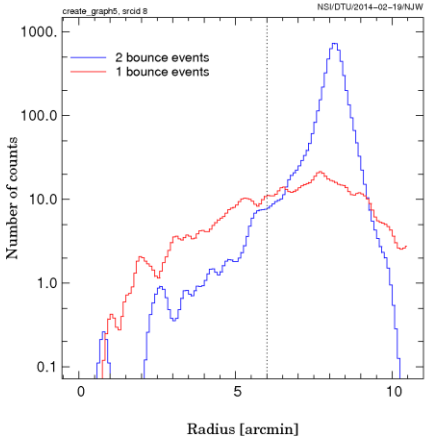
The single bounce events have here been shown with red dots.



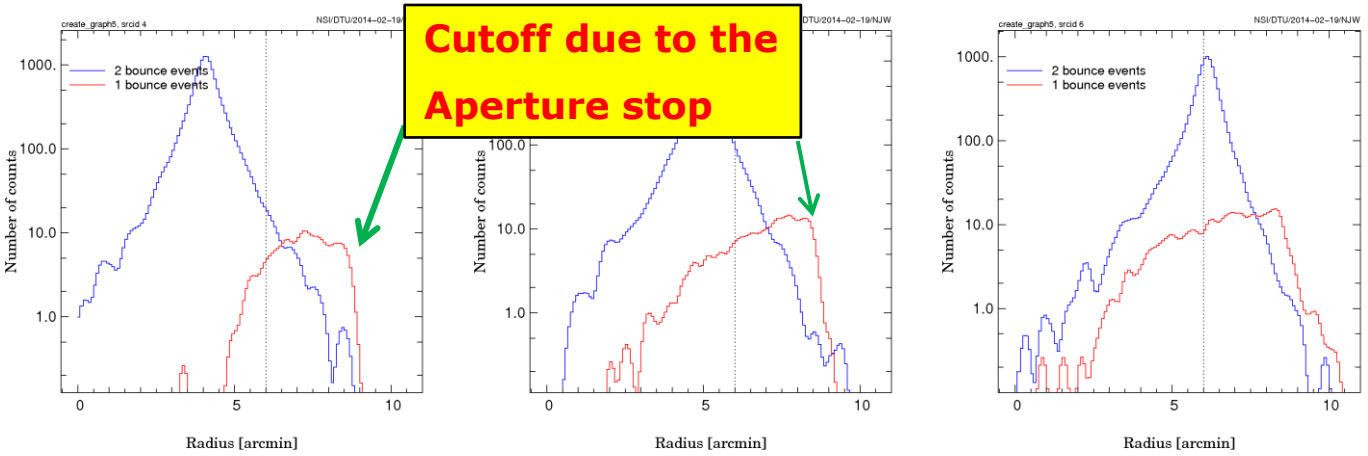


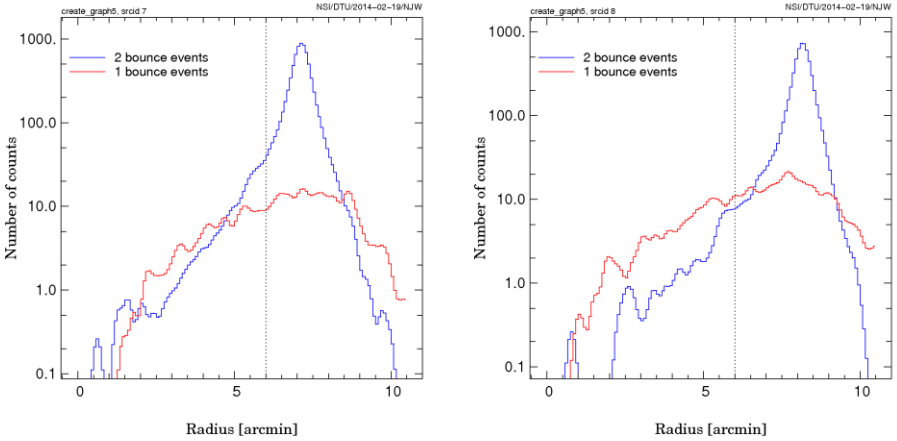






The radial distributions of counts for the cases showed in the previous slide

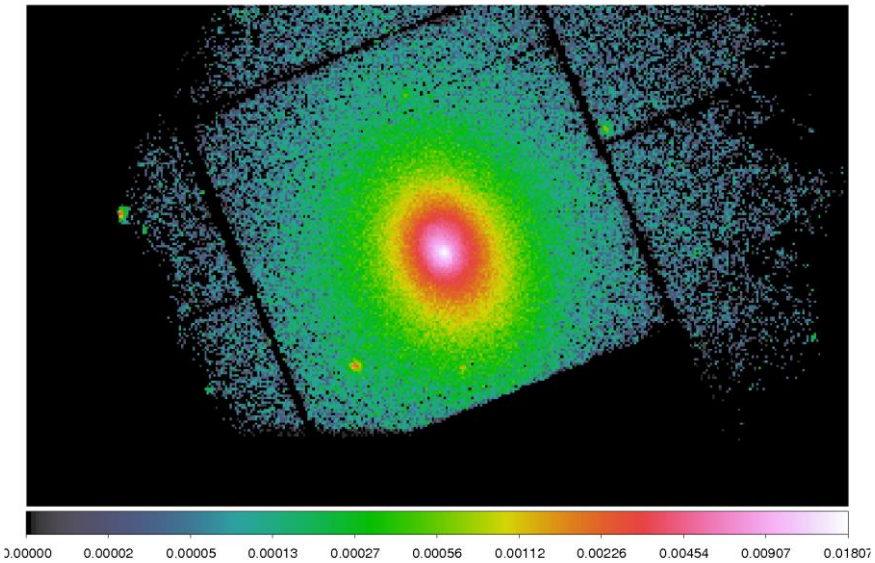




The radial distributions of counts for the cases shown in the previous slide.

On the Abell 2029 Cluster

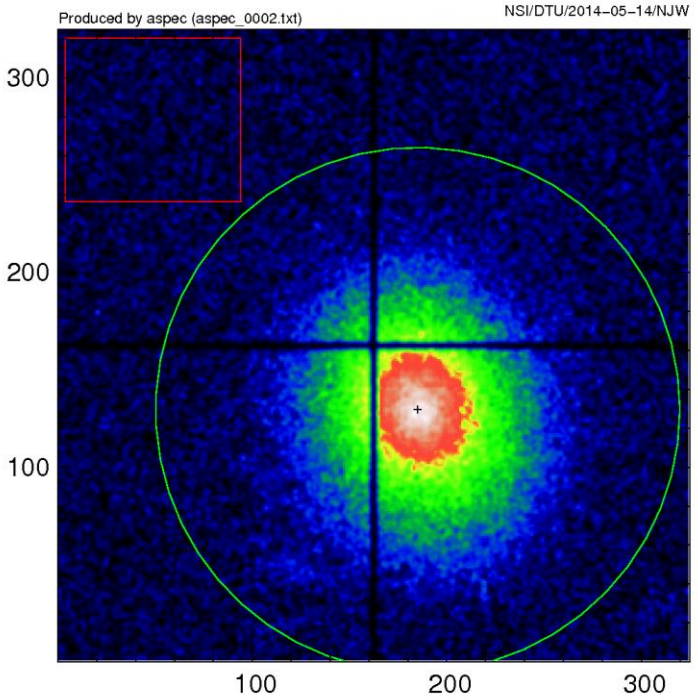
Hot, nearby, large cD galaxy



XMM MOS1 countrate image

0.5 – 12 keV, vignetting corrected

(log color scale in both figures)

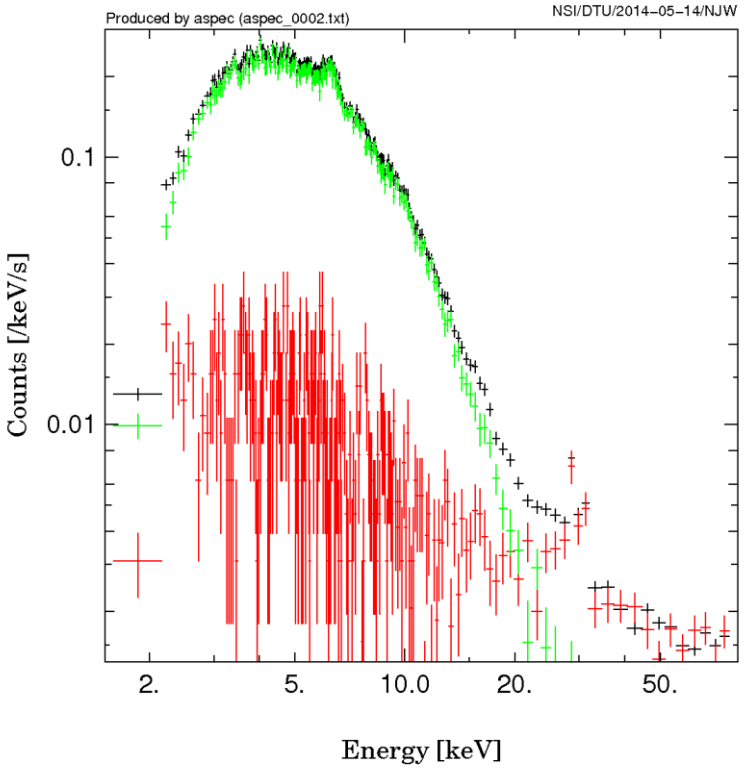


Simulated NuSTAR observation in a single instrument.

Exposure = 60 ks

Countrate = 1.5 cts/s

All energies, region radius is 5.5 arcmin



The all-cluster spectrum in NuSTAR.

phabs*mekal

z = 0.0767

abun = 0.2

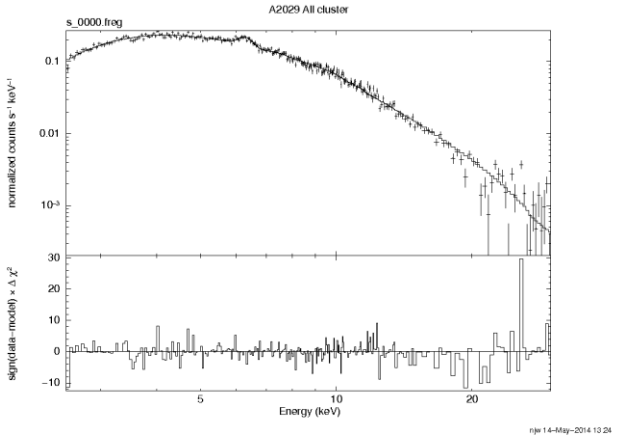
N_H = 0.0326

kT = 9.1 keV

Walker, Fabian et al. MNRAS 2012

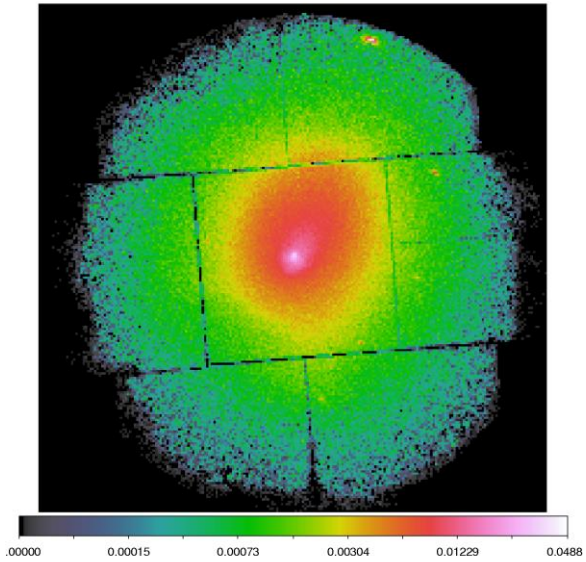
XSPEC fitting renders

kT = 9.0 ±0.1 keV



On the Ophiuchus Cluster

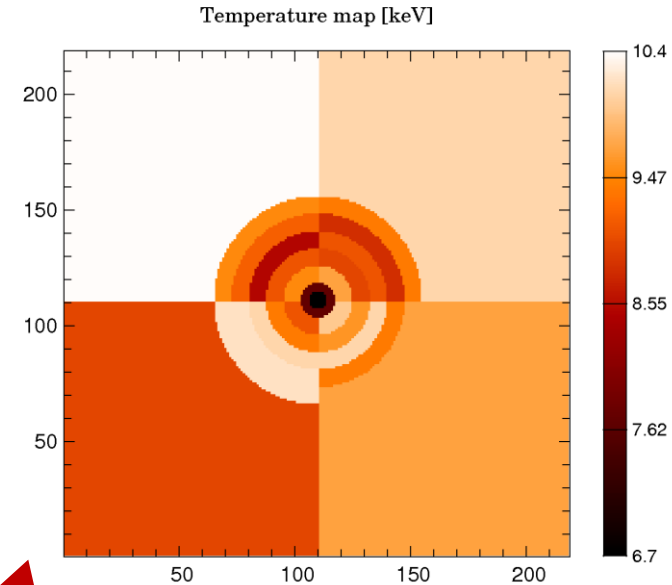
Hot, nearby, cooling core

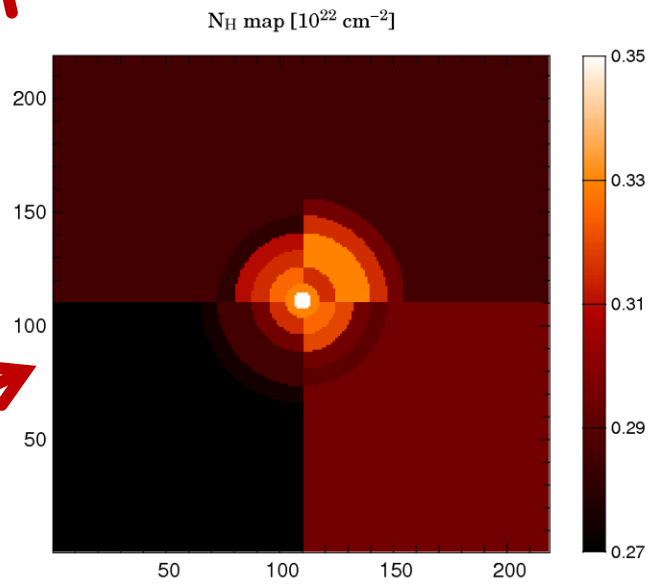


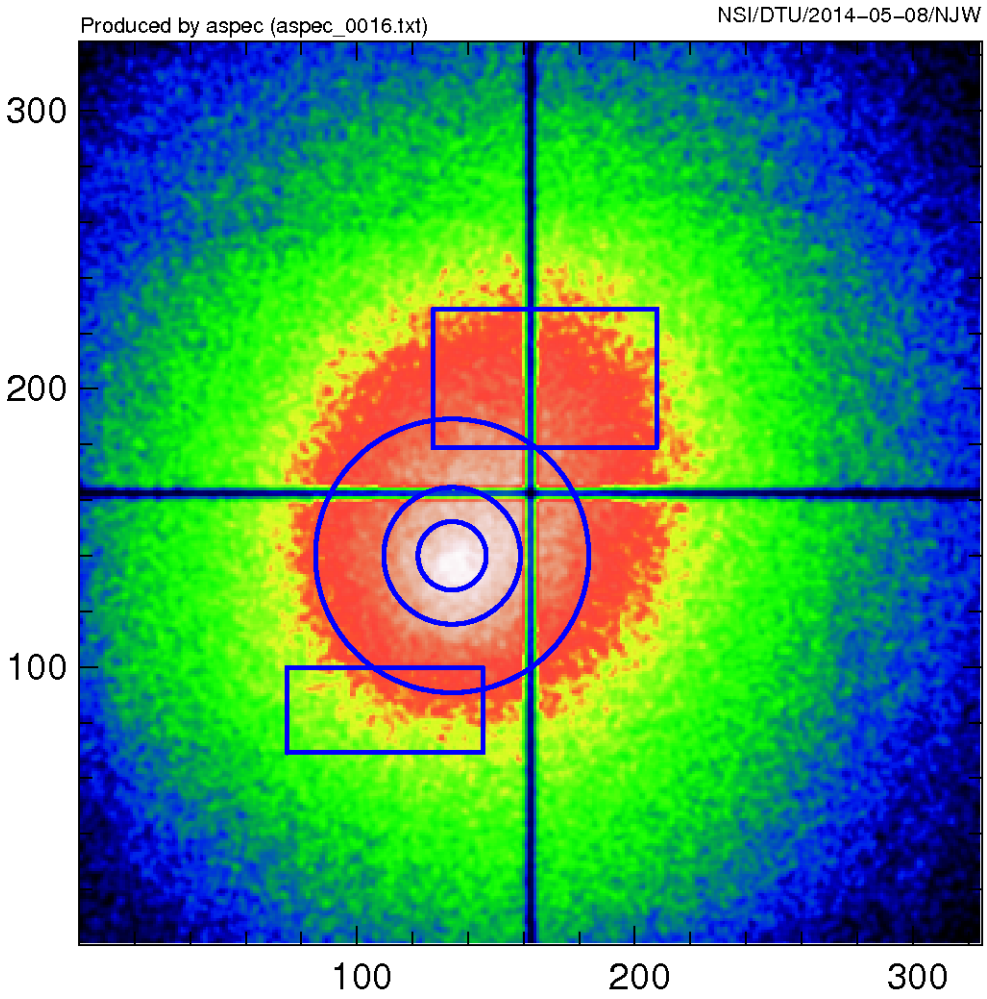
XMM MOS2 countrate

Image (log color scale)

Nevalainen et al., AA 2009





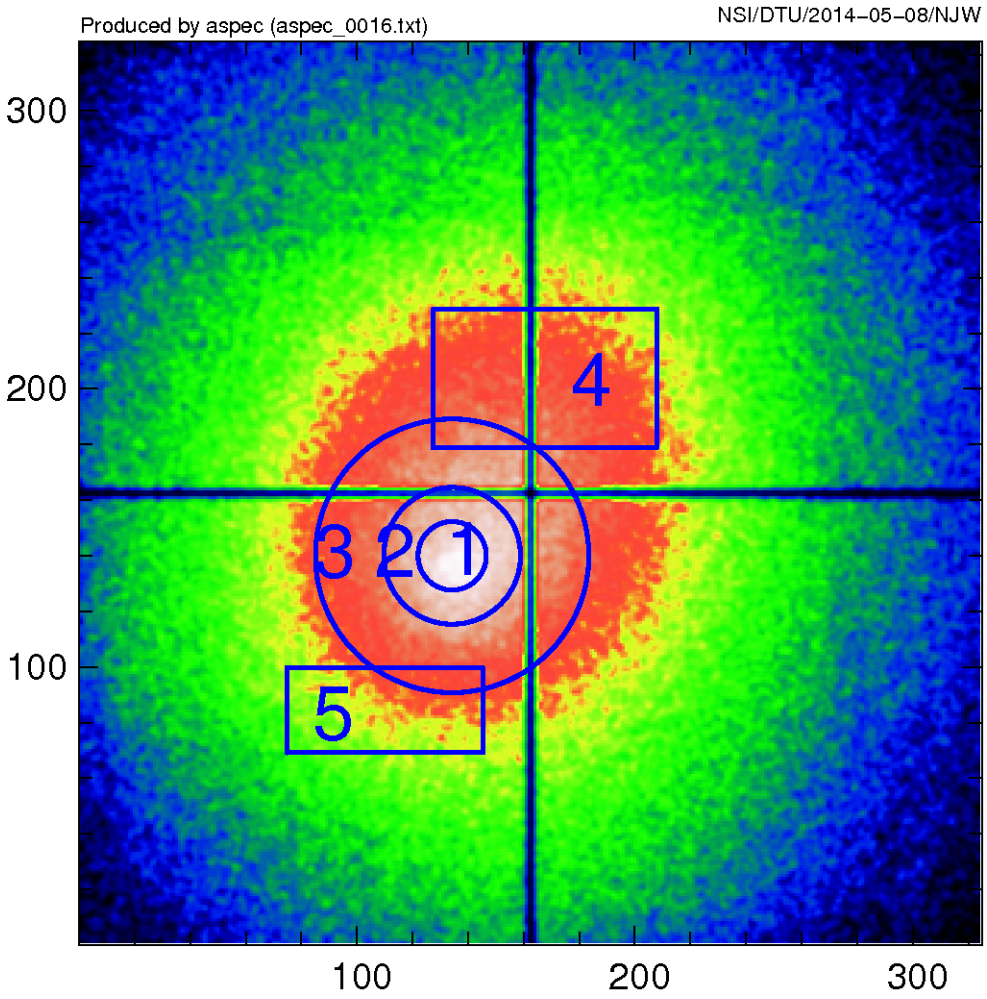


A simulated NuSTAR observation in a single instrument with an exposure of 100 ks.

All energies, no background.

Colorscale is logarithmic and the circular regions match the JN inner sectors.

Total countrate is 7 cts/s



A simulated NuSTAR observation in a single instrument with an exposure of 100 ks.

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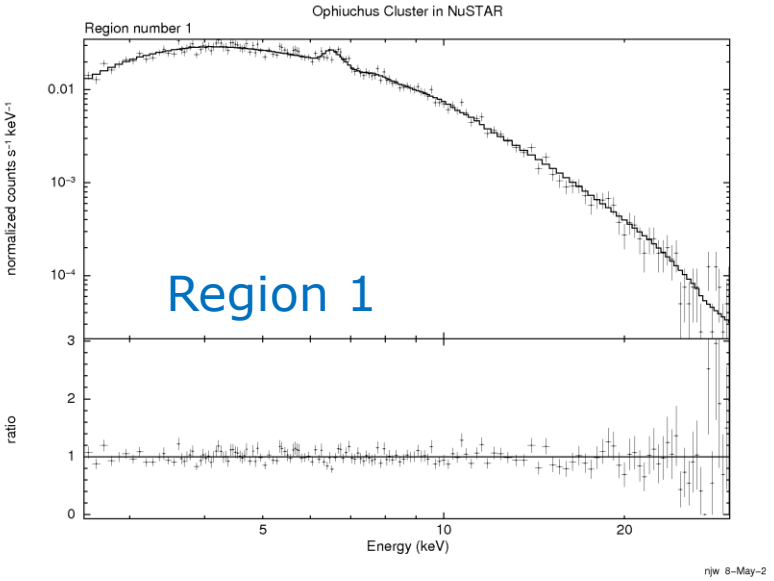
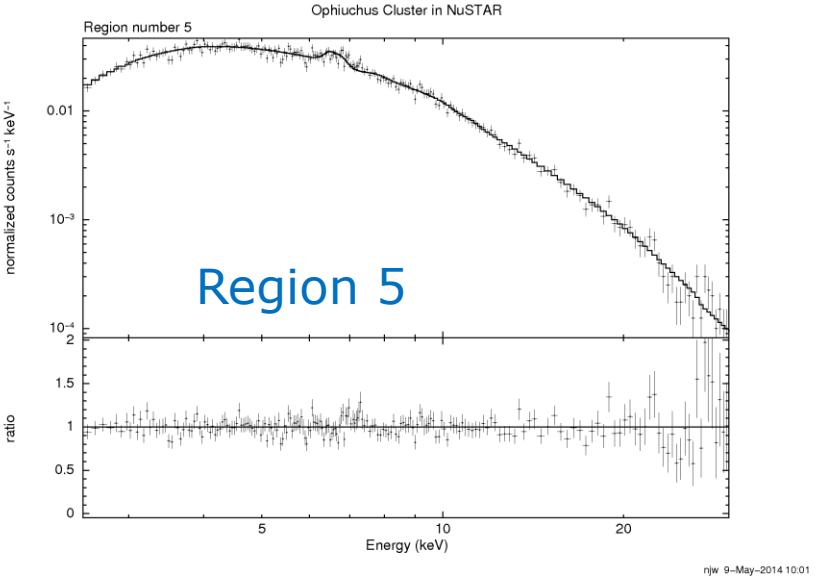
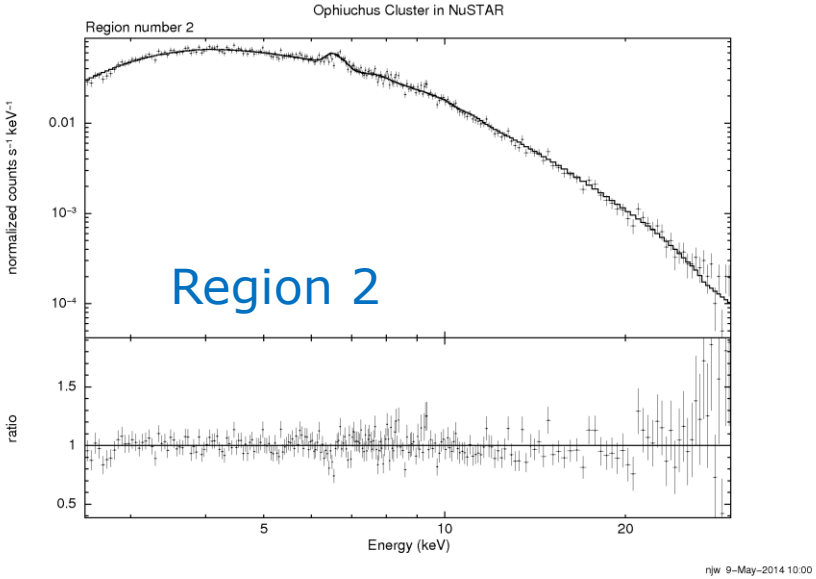
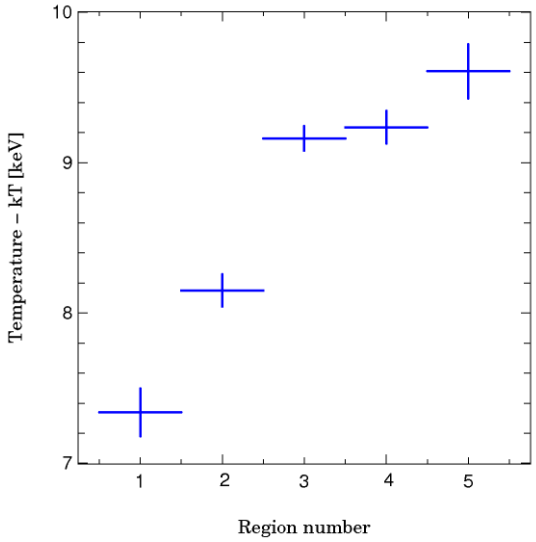
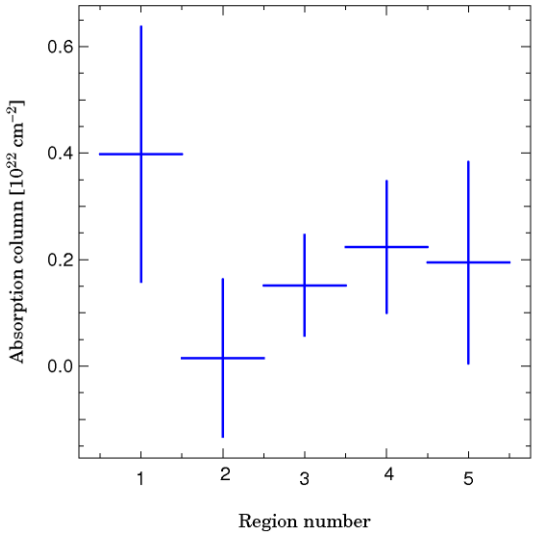
Total countrate is 7 cts/s


Ophiuchus Cluster in NuSTAR
Region number 1
normalized counts s⁻¹ keV⁻¹
ratio
Energy (keV)
njw 8-May-2
Region 1


Ophiuchus Cluster in NuSTAR
Region number 5
normalized counts s⁻¹ keV⁻¹
ratio
Energy (keV)
njw 9-May-2014 10:01
Region 5


Ophiuchus Cluster in NuSTAR
Region number 2
normalized counts s⁻¹ keV⁻¹
ratio
Energy (keV)
njw 9-May-2014 10:00
Region 2

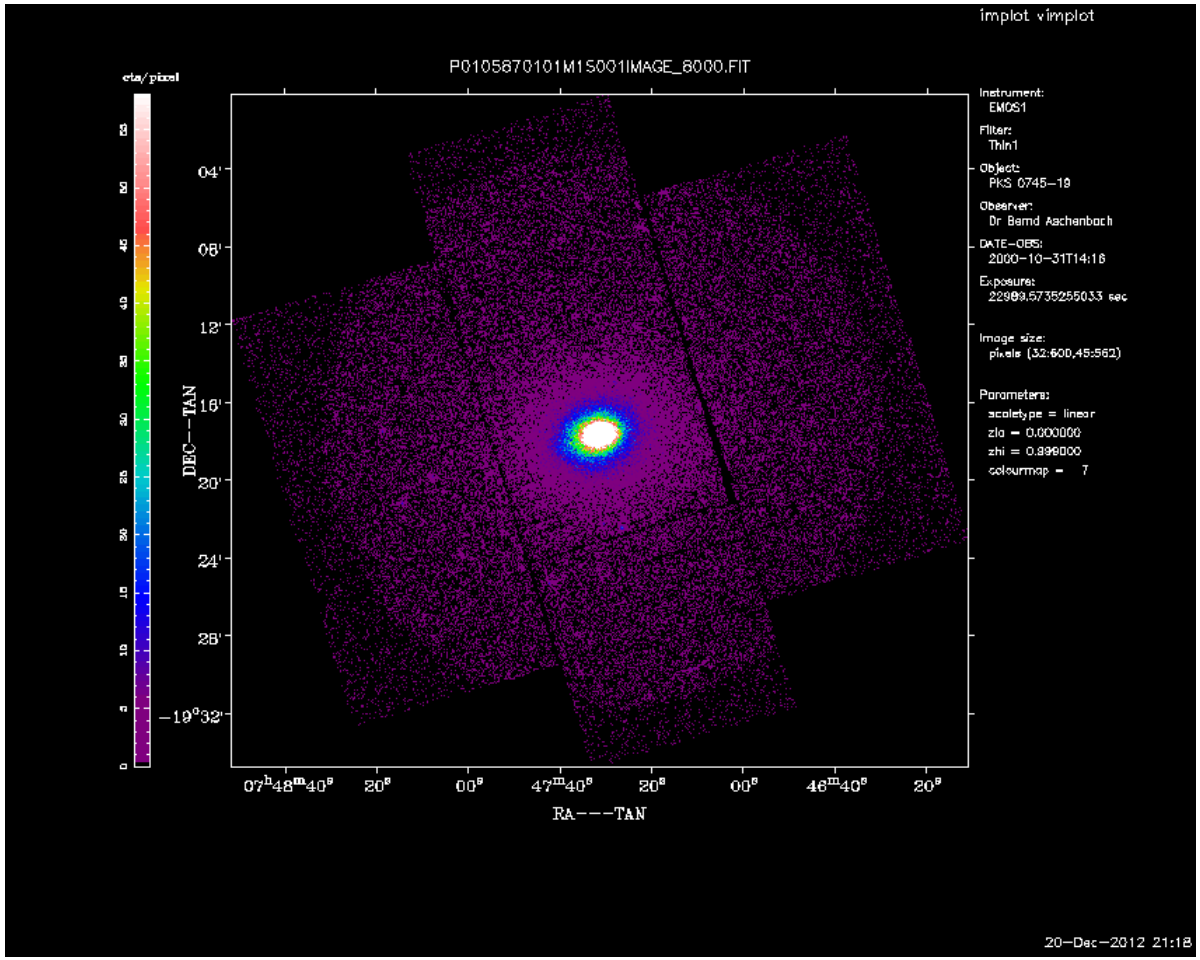




The temperature determination is good for these high temperatures. There is some crosstalk between the regions.

With a lower energy limit of 2.5 keV NuSTAR is less sensitive to the absorption column.

Ready to do PKS0745-191, z=0.1028



Cluster coordinates

Name	HMS	DMS	RA-deg	Dec-deg
Bullet Cluster	13 49 0.5	26 35 07	207.252	26.585
Abell 2256	17 03 43.5	78 43 03	255.931	78.718
Coma cluster	12 59 48.7	27 58 50	194.953	27.981
Coma shock				
Ophiuchus	17 12 24.7	-23 21 01	258.103	-23.350
Abell 2029*	15 10 58.7	05 45 42	227.745	5.762

*) optical position, X-ray peak at 227.734 5.744

Comments for A1795

The resulting flux is 4.73 10^{-11} erg/cm2/s between 2 and 10 keV

The literature seems not to reveal the XMM or Chandra derived flux but an old result by Mushotzky (1984) quotes a luminosity of 11 10^{44} erg/s (2 – 10 keV) which translates to 6.5 10^{-11} erg/cm2/s. This is not an exact match but good enough to corroborate the simulation results.

A NuSTAR observation of this duration or even shorter should give enough counts for an adequate inter-calibration result and the prospects for investigating the temperature profile are quite good.