RGS/EPIC cross calibrations

- Introduction (purpose and method)
- PKS2155-304 and Mrk 421
- Conclusions

in progress and will be updated when instrument response improves

J.W. den Herder, J. Kaastra, T. Tamura, C. de Vries (SRON), A. Rasmussen (Columbia),

U. Briel, F. Haberl (MPE), G. Griffiths, S. Sembay (Leicester), F. Ferrando (Saclay),

S. Molendi, S. Ghizzardi (IFCTR), D. Lumb (ESA)

columbia

05.12.01

purpose

- Compare relative effective area for RGS, EPIC-MOS and EPIC-pn over relevant energy domain (0.3 to 2 keV) for a selected set of EPIC instrument modes:
  - Filters (thin, medium, thick)
  - Operational modes PN (SW)
  - Operational modes MOS (SW, SW/free)

MOS SW/free: a-linearity of DA converter is not corrected and hence the spectra should be binned in 75 eV bins at least, not relevant for continuum sources

- Excluded are differences between RGS1/RGS2 and MOS1/MOS2

columbia

method (1)

- Select simultaneous periods for all instruments
- Select parts of the PSF not influenced by pile-up effects and correct for the corresponding energy dependence of spatial selections (required as corresponding selections in RGS are not feasible)
- Use energies between 0.3 and 10 keV only to reduce sensitivity of the analysis for background variations

columbia

method (2)

- Compare results between currently best knowledge (which is different from what is available in the public software).
  - RGS: m=-1, including β correction for RGS1 and the model of the O-edge.
  - EPIC-pn: usage of the corrected CTI for SW (responses epn_sw20_s/dY9_filter.rsp, version 6.1 (= singles and doubles)
  - EPIC-MOS:m<#>_<filter>v9q20t5r6_<pat>_15.rsp where <pat> = ‘p0’ for singles and ‘all’ for patterns ≤ 14

columbia

Energy dependence encircled energy

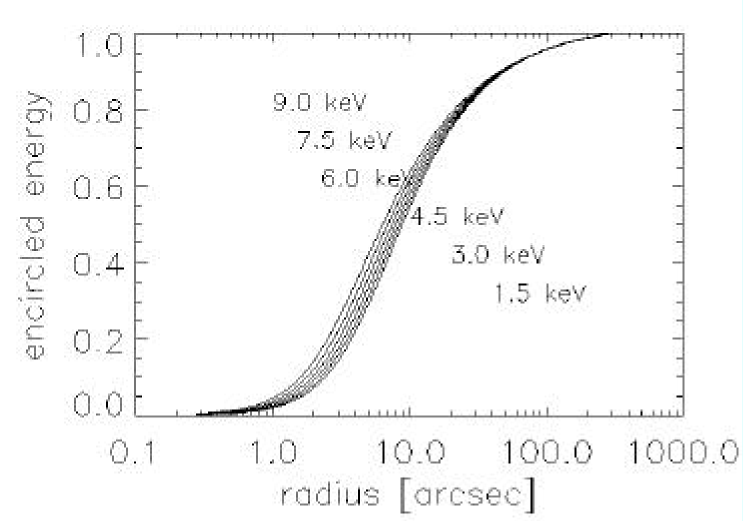
- Pile up effects:

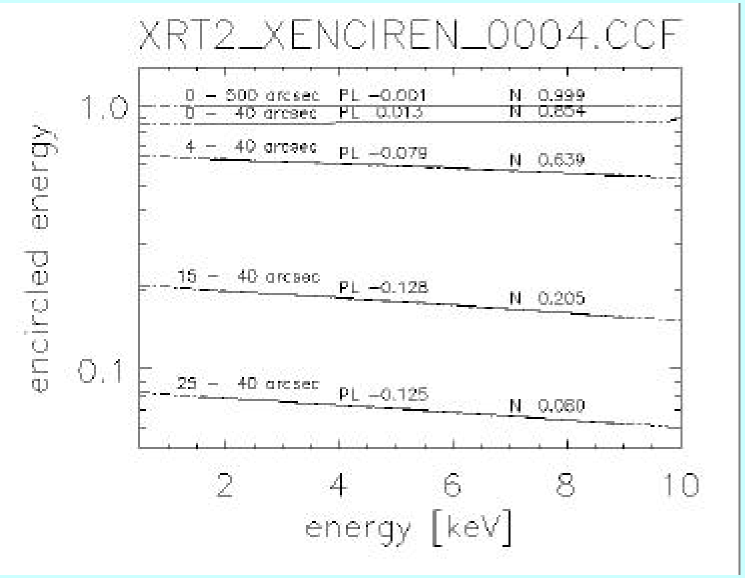
  exclude central part and check ratio singles/doubles

- Energy dependence of encircled energy:

  need for energy dependent corrections for different spatial selections (normalization and slope, different per telescope, see poster Ghizzardi)

  (CCF XRTi_XENCIREN_003/4)





columbia

05.12.01

PKS 2155

- BL Lac, $N_H = 1.27\ 10^{20}\ cm^{-2}$ (from Chandra)
- Model: power law (consistent with simultaneous Chandra-LETG/HRC-S observation for orbit 87)

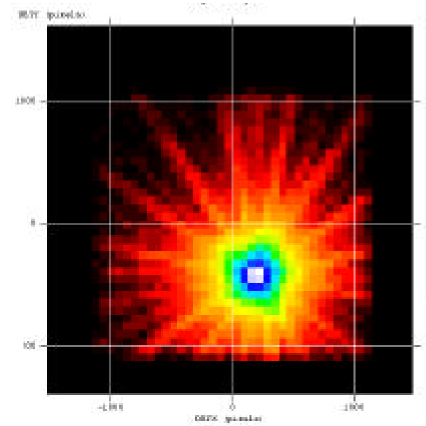
- Usage of guaranteed time but is now also part of the routine calibrations:

Orbit	pn		mos1		mos2		ks
87a	medium	SW	medium	SW/free	*(medium*	*timing)*	35
87b	medium	SW	*(medium*	*timing)*	medium	SW/free	56
174a	thin	SW	*(thin*	*timing)*	thin	SW	46
174b	thin	SW	*(thin*	*timing)*	thin	SW	37

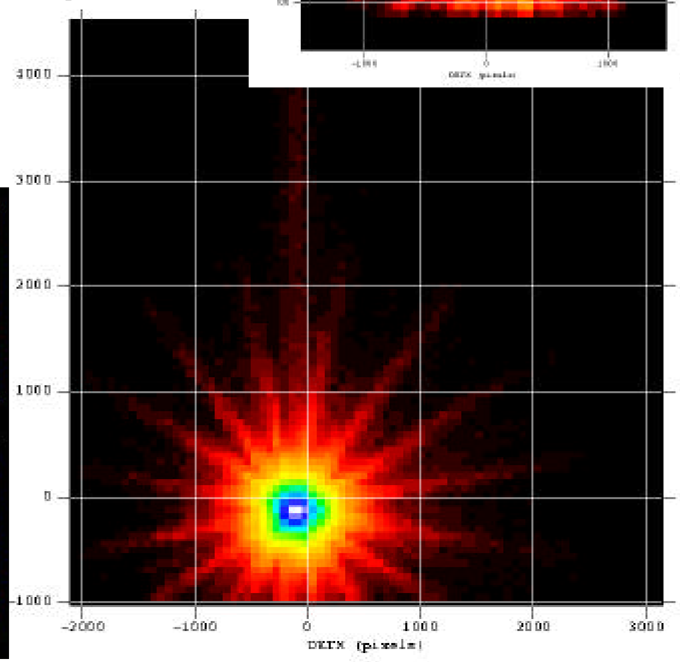
PKS 2155, orbit 87 images

- Select pattern ≤ 4 (PN) and ≤ 12 (MOS)
- Select regions between 15 – 40”
- No data gaps, no high background periods
- No background subtraction

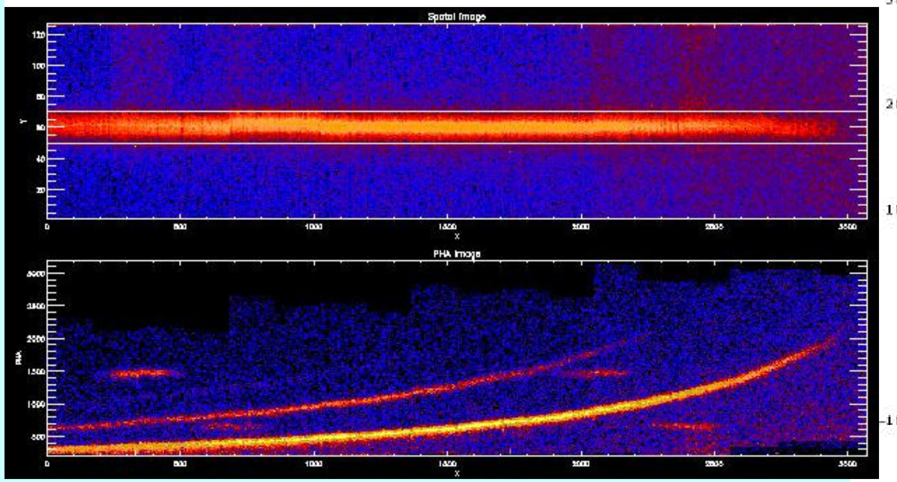
MOS1 SW/free



pn SW



RGS2

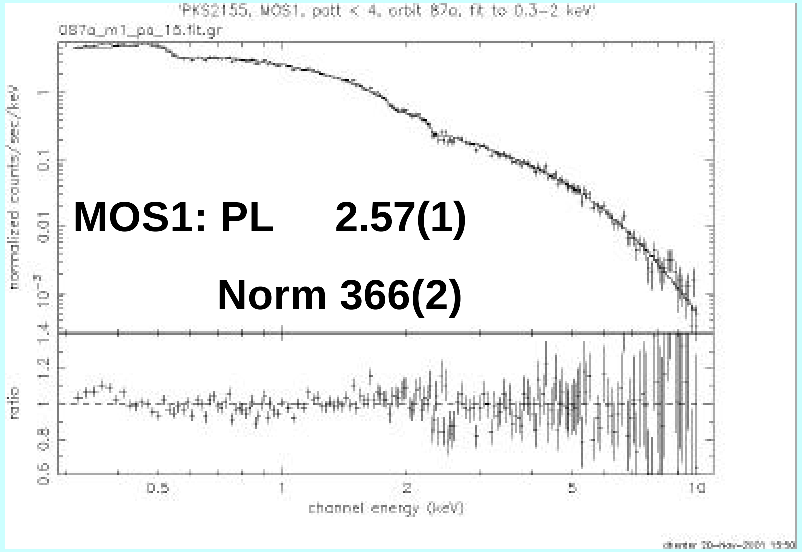


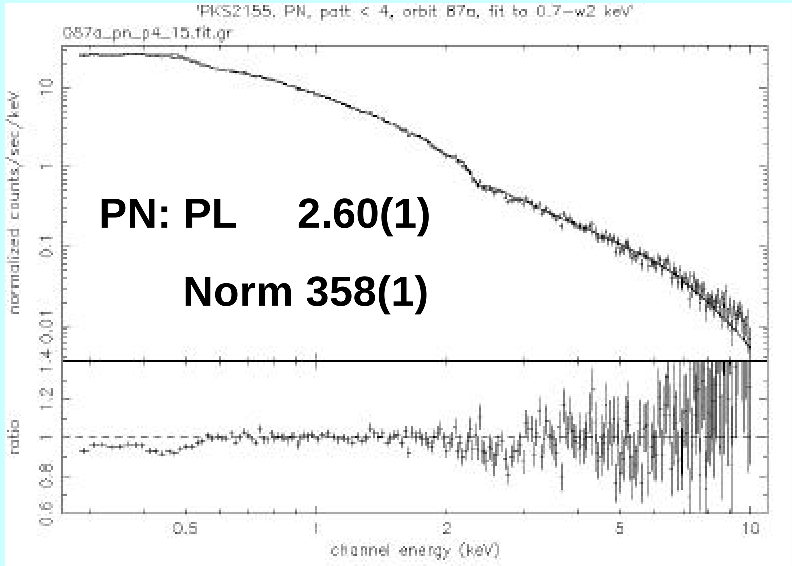
PKS 2155 orbit 87: EPIC spectra

- Single power law + galactic absorption gives a good description for MOS1 ($\chi^2_r \approx$ 1.7 for 0.3-10 keV) and for PN ($\chi^2_r \approx$ 1.4 for 0.7 – 10 keV).

- Variation of N_H (1.27 ± 0.2 10^{20} cm^{-2} has small effect on PL (< 0.01) and on normalization (< 1.5%)

- PN SW only reliable above O-edge (> 0.7 keV), difference below O-edge due to not yet properly calibrated CTE correction

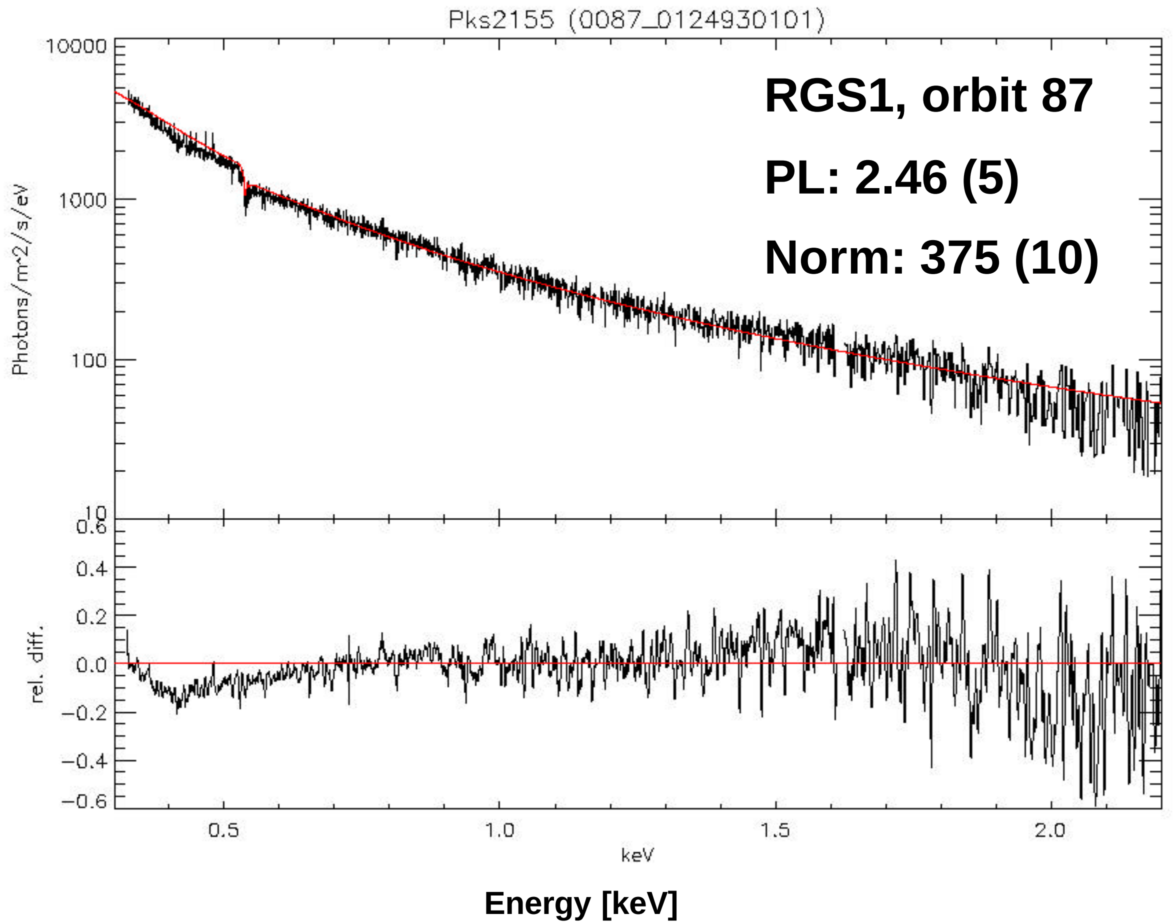




columbia

05.12.01

PKS2155-304: RGS spectrum



columbia

05.12.01

PKS 2155-304: comparison
(15-40 arcsec)

Power law

orbit	pn		MOS1		MOS2		RGS	D
energy	**0.7-2**	**0.7-10**	**0.3-2**	**0.3-10**	**0.3-2**	**0.3-10**	**1+2**	**E-R.**
87a	2.59(1)	2.60(1)	2.56(1)	2.57(1)	-	-	2.46(5)	0.02
[pat 0:	2.59(2)	2.61(1)	2.57(1)	2.58(1)]				
87b	2.54(1)	2.53(1)	-	-	2.55(1)	2.56(1)	2.46(5)	-0.02
174a								0.08
174b								0.08

Normalization

orbit	pn		MOS1		MOS2		RGS	ratio
energy	**0.7-2**	**0.7-10**	**0.3-2**	**0.3-10**	**0.3-2**	**0.3-10**	**1+2**	**E/R**
87a	358(10	358(1)	367(2)	366(2)	-	-	375(10)	0.97
87b	379(1)	378(1)	-	-	366(1)	365(1)	375(10)	0.99
174a								0.96
174b								0.97

columbia

Intermediate conclusions

- Different patterns give similar results.
- Mismatch between data and single power law < 5% over range between 0.3 and 10 keV for MOS and PN and only up to 10% for PN between 0.3 and 0.7 keV. Residuals follow gold reflection coefficients.
- Normalizations between MOS, PN and RGS consistent.
- Slope RGS smaller than for EPIC (but within error bars).
- Simultaneous calibration with Chandra performed (orbit 87) and planned. Detailed analysis pending.

columbia

Markarian 421

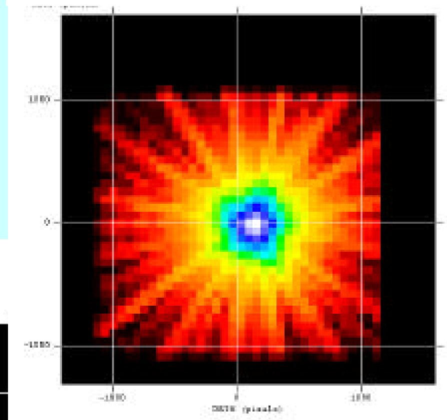
- BL Lac, z=0.031, N_H =1.68 10^{22} cm^{-2} (Chandra results) (see also Brinkmann et al., A&A 371,orbit 84)
- Model: power law (suggested by Chandra data) or broken power law (see Brinkmann)
- Source is observed for monitoring effective area changes in RGS.
- As the source is very bright larger exclusion region is required (25 – 40 arcsec)
- Repeated observations :

Orbit	pn		MOS1		MOS2		ks
84	**thick**	**SW**	**-**	**-**	medium	SW/free	**24**
165	**thick**	**SW**	**medium**	**SW**	**medium**	**SW**	**36**
171	**thick**	**SW**	**medium**	**SW**	**medium**	**SW**	**46**
259	thin	SW	thin	SW	thin	SW	37

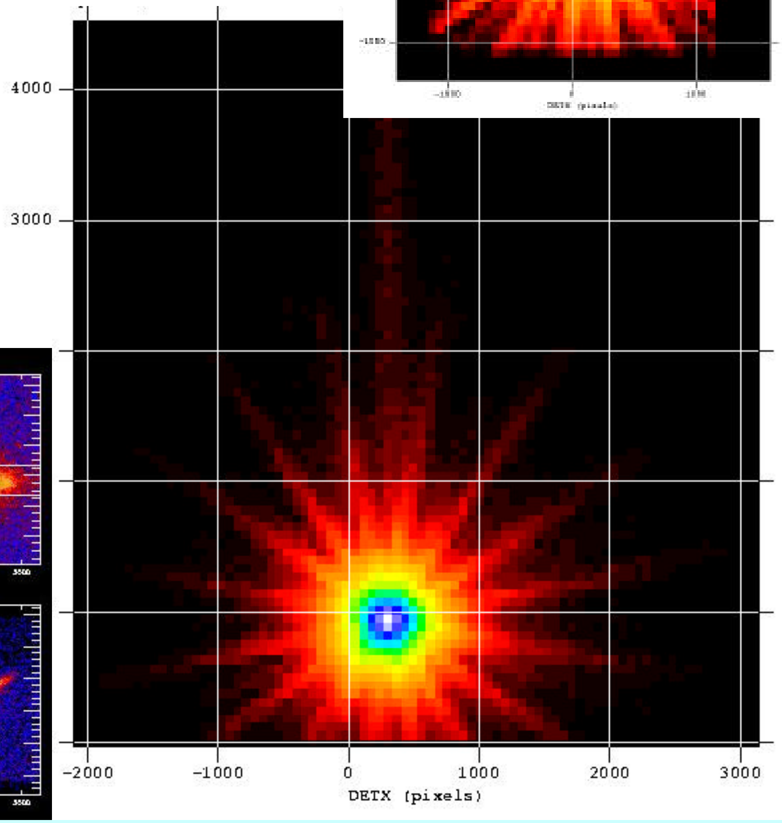
Mrk 421 (orbit 165)

- Only pattern ≤ 4 (PN) and ≤ 12 (MOS).
- Source is significantly brighter (factor 4 to 5). Hence 25 – 40 arcsec are selected

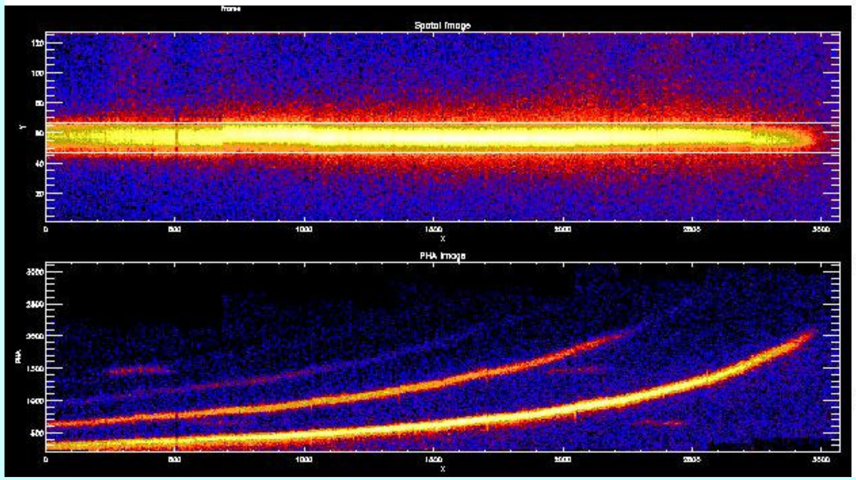
MOS1: SW



pn: SW



RGS2



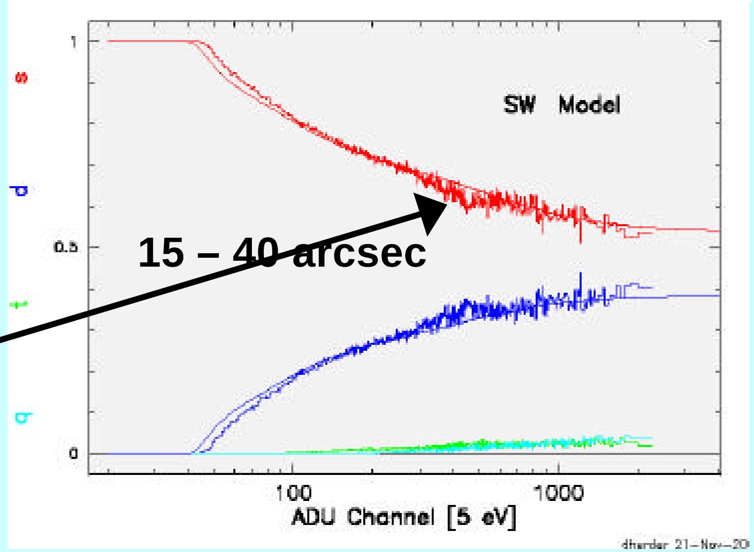
columbia

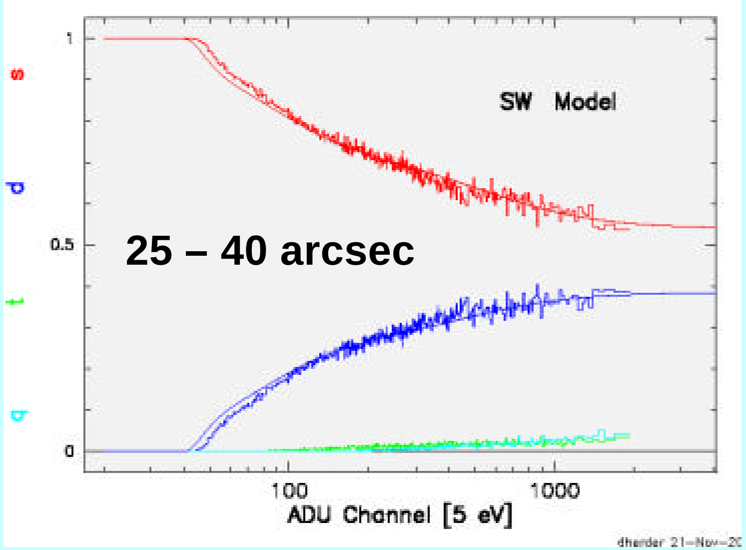
Mrk 421: pile up in the core

- Pile up in the core (source is about factor 5 brighter
- Select 25 – 40 arcsec

SAS, v 5.2

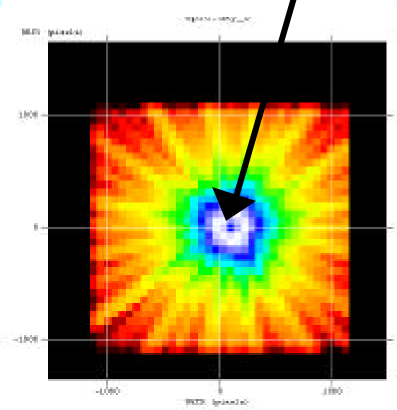
Pile up in PN



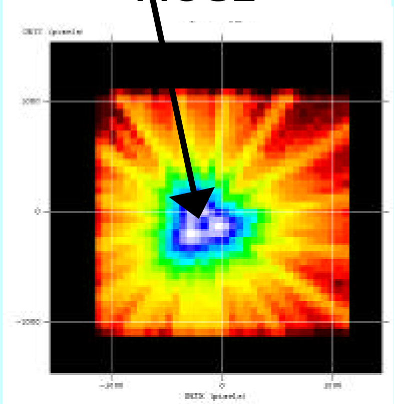


Pile up in MOS

MOS 1



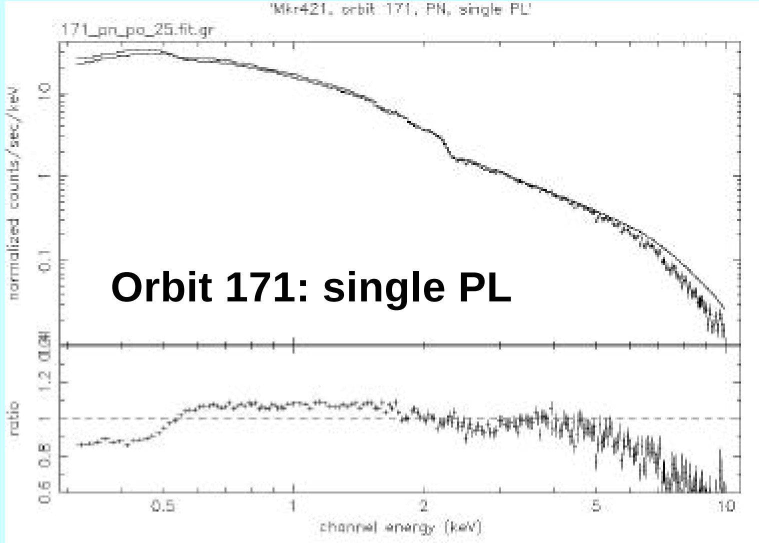
MOS2

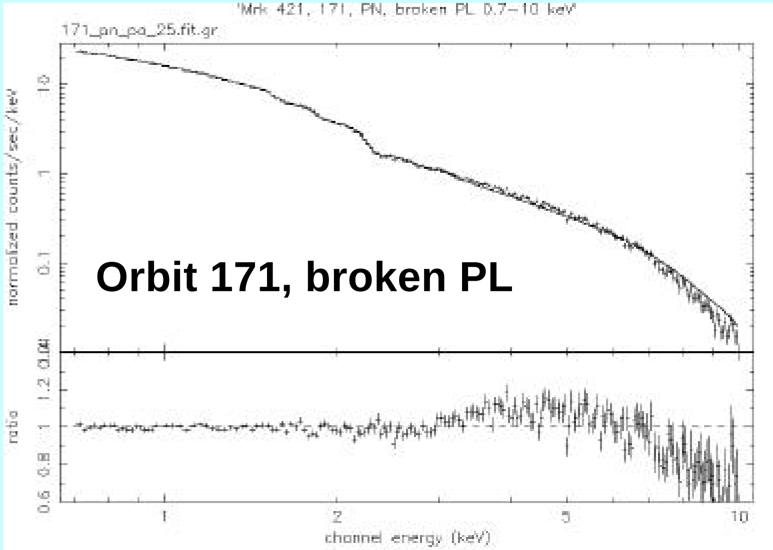


columbia

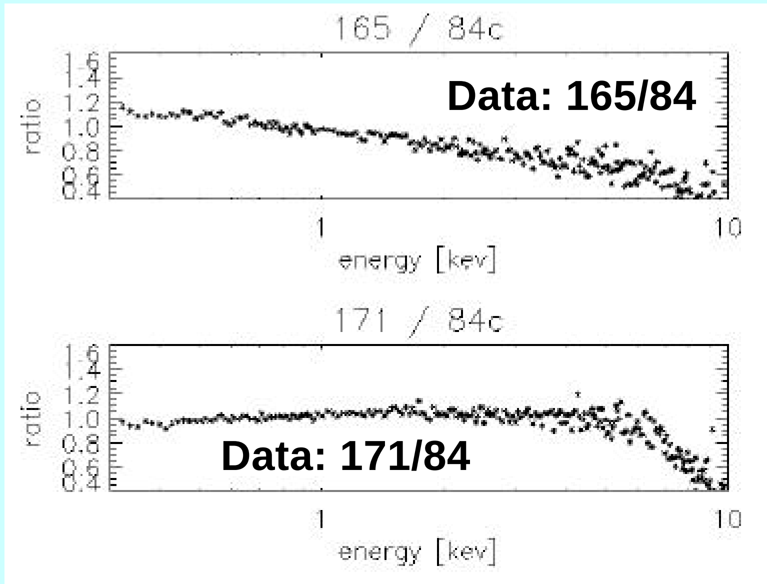
05.12.01

Mrk 421: spectral shape and variability (PN data)





- Source variable in intensity, spectral shape and break energy (varying)
- EPIC/RGS comparison over limited energy range feasible

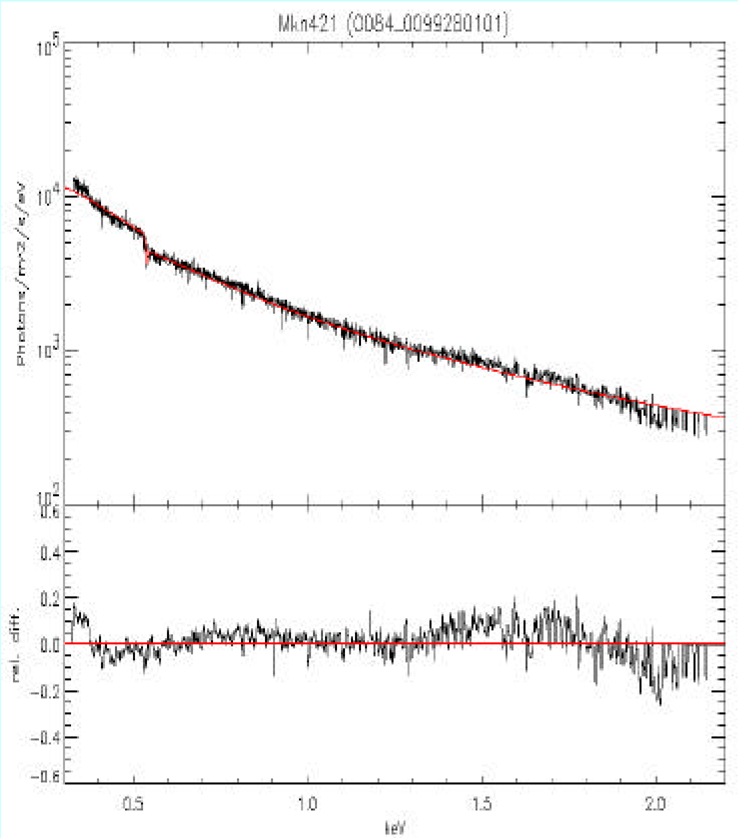


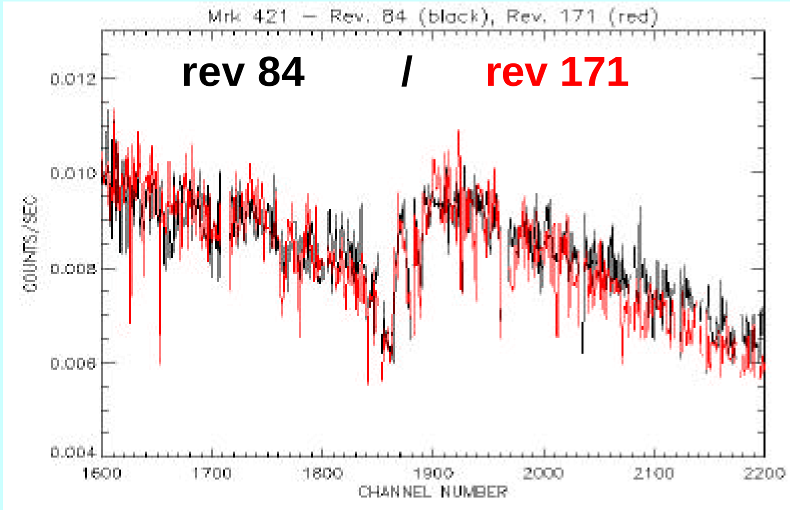
columbia

05.12.01

Mrk RGS spectra

- Power law gives good description within 10% and instrument response is stable over time





columbia

Mrk 421 comparison
(single PL, 25-40")

Power law

orbit	pn		MOS1		MOS2		RGS	D
energy	0.7-2	0.7-10	0.3-2	0.3-10	0.3-2	0.3-10	1+2	E-R
84	2.37(1)	2.34(1)	-	-	-	-	2.20(5)	0.05
165	2.53(1)	2.58(1)	2.45(1)	2.48(1)	2.46(1)	2.50(1)	2.20(5)	0.17
171	2.31(1)	2.39(1)	2.17(1)	2.24(1)	2.20(1)	2.26(1)	2.06(5)	0.06

Normalization [ph/keV/m^2]

orbit	pn		MOS1		MOS2		RGS	E/R
energy	0.3-2	3-10	0.3-2	3-10	0.3-2	3-10	1+2	ratio
84	2962(6)	2946(6)	-	-	-	-	1400	
165	656(3)	657(3)	655(3)	650(3)	632(3)	626(3)	660(10)	0.98
171	2206(4)	2219(5)	2178(4)	2141(4)	2245(4)	2208(4)	2070(10)	1.07

- **Fraction encircled energy 8%**
- **RGS during orbit 84 in special mode which affects normalization (not the slope)**

columbia

conclusions

- Comparison needs to address pile up and special EPIC modes (SW) which introduces additional uncertainties (effect of pile-up events and of spatial selections).

- **Slope:** **RGS = EPIC – 0.06(5)**
- **Normalization:** **RGS = (0.97 ± 0.03) EPIC**

- Within expected accuracies (± 10 % for MOS/RGS over the range of 0.3 to 2 keV and ± 10 % for PN/RGS but over an energy range of 0.7 to 2 keV) instrument models for effective area agree.

- Remaining differences between source models and instrument response follow the gold reflection coefficients and are most likely instrumental and can probably be corrected

columbia

Energy dependence of spatial selections

Power law

Spatial	XRT1	XRT2	XRT3	average
0-500 arcsec	0.001	-0.001	-0.002	-0.001(1)
0-40	0.005	0.013	0.021	0.013(8)
4-40	-0.092	-0.079	0.004	-0.057(50)
15-40	-0.130	-0.128	-0.077	-0.112(30)
25-40	-0.118	-0.125	-0.115	-0.119(5)

normalization

Spatial	XRT1	XRT2	XRT3	average
0-500	0.999	0.999	0.983	0.994(9)
0-40	0.877	0.854	0.853	0.861(14)
4-40	0.659	0.639	0.671	0.656(16)
15-40	0.199	0.205	0.213	0.206(7)
25-40	0.077	0.080	0.083	0.080(3)

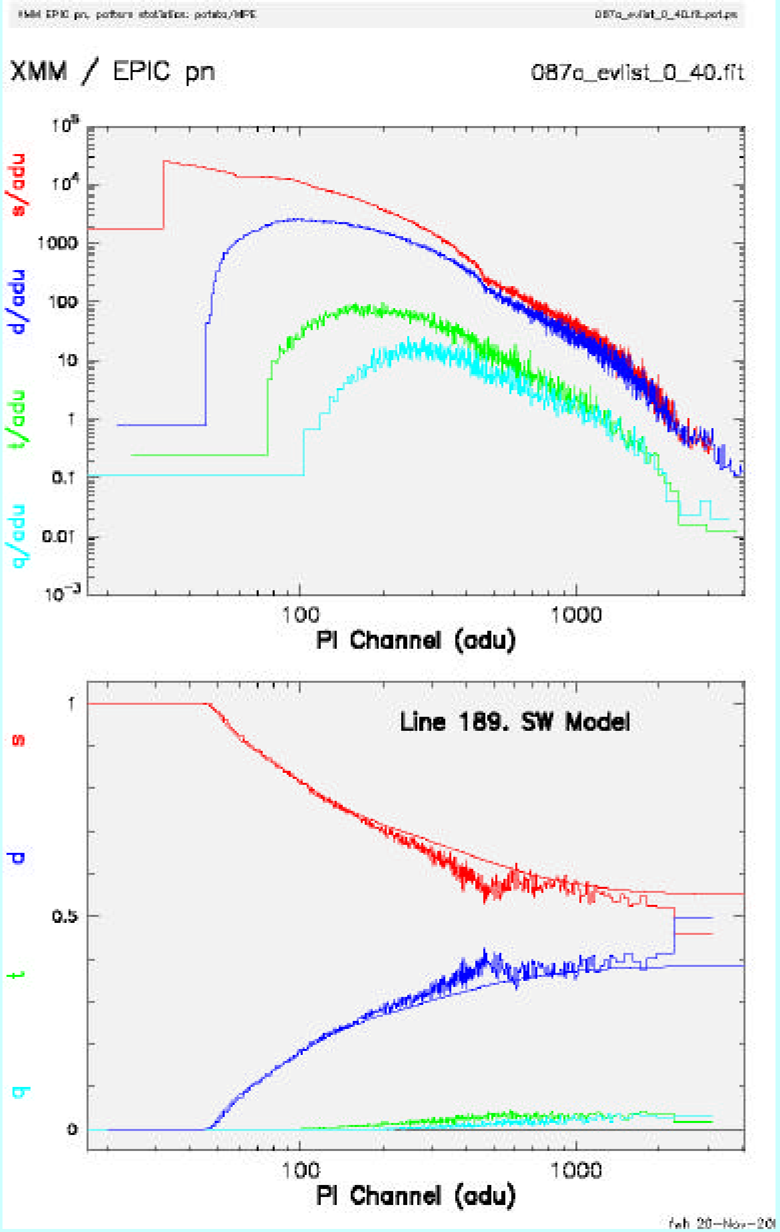
columbia

05.12.01

Energy dependence of event patterns

- When there is no pileup, the ratio of singles over pattern 1-4 can be predicted. Due to pileup the number of complex patterns (> 0) can be larger than expected (roughly at twice the peak energy).

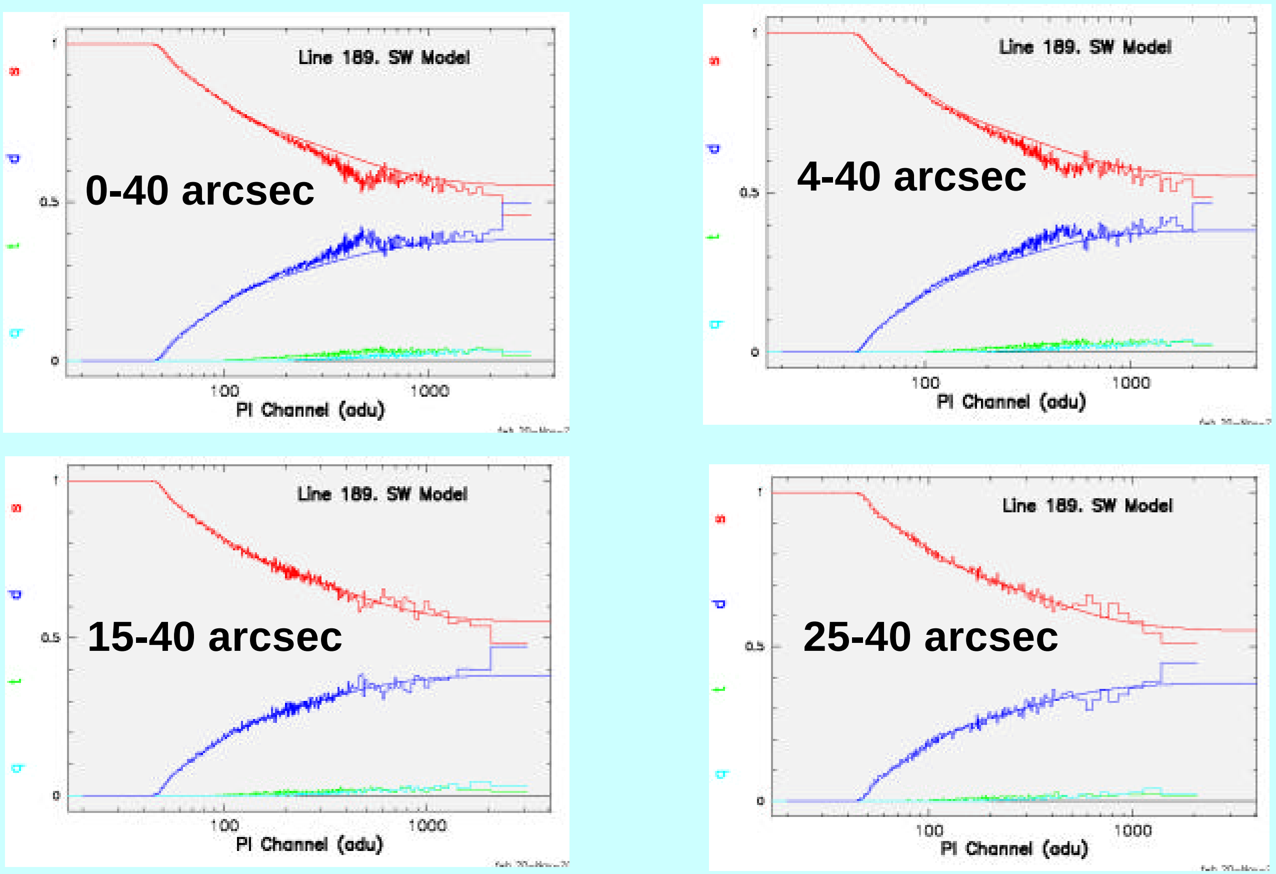
- This can be used to verify the size of the central part of the source which needs to be rejected.



columbia

Pileup: PKS2155

- Shown are the relative fractions of singles, doubles, triples and quadruples for an observation of PKS 2155. Deviations from the model are due to pileup and are virtually absent for the 15-40” selection



columbia

05.12.01

PKS 2155/Chandra

- Simultaneous observation of XMM and Chandra/LETGS(HRC)
- Subtraction of higher orders from data using bootstrap method
- Select period of low background
- Ratio PKS2155/Mrk 421 is very smooth between 5 and 60A: assume PKS 2155-304 and Mrk 421 are unbroken powerlaws (unlikely they have the same break energy)