XMM-Newton SOC Technical Note

XMM-SOC-CAL-TN-0082

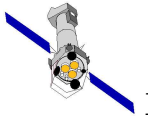## Accuracy of energy reconstruction in EPIC-MOS Timing Mode

M. Guainazzi

April 6, 2009

History

Version	Date	Editor	Note
1.0	April 6, 2009	M.Guainazzi	SASv8.0

1   Motivation and methodology

In the report I study the accuracy of the energy reconstruction in EPIC-MOS Timing Mode. For this purpose I analyzed the spectra of two bright, line-rich SuperNova Remnants (SNRs: Cas A, and N132D) observed before the micro-meteoroid impact in Rev.#961 (Guainazzi 2009). The centroid energy of the strongest emission lines measured in these spectra has been compared with that simultaneously measured by EPIC-pn Full Frame exposures and with exposures of the same targets taken in MOS imaging modes (Full Frame and Large Window; Sect. 3.1). The nominal energy reconstruction accuracy in imaging modes is ± 10 eV for the three EPIC cameras over their whole sensitive bandpass (Guainazzi 2009).

Furthermore, the best-fit phenomenological model for the RGS spectra of the star AU Microscopii (Rev.#155) has been compared with a simultaneous MOS2 Timing Mode spectrum, to cross-check that the results obtained with the aforementioned reference targets are not affected by the extended nature of their X-ray emission.

2   Data reduction

Table 1 shows the list of observations discussed in this report. In Obs.#0129341101 and #0165560101

Table 1: List of observations discussed in this report

Source	Obs.#	MOS mode
N132D	0129341101	Timing
N132D	0210681301	Full Frame
N132D	0157160301	Large Window
CasA	0165560101	Timing
CasA	0097610501	Large Window
AU Microscopii	0111420101	Timing[a]

[a]only MOS2

the EPIC-MOS cameras were operated in Timing Mode, while the EPIC-pn camera was operated in Full Frame Mode. Given the large extension of these sources (>1') the pile-up fraction is negligible in all exposures [Bleeker et al. (2001) estimate an EPIC-pn pile-up fraction <3% in the brightest knots of Cas A, for instance].

Data were reduced with SASv8.0 (Gabriel et al. 2003)[1], using the most updated calibration files available at the date of the report's publication. Standard screening criteria were applied to the data, as defined by the `#XMMEA_EM` and `FLAG==0` selectlib expressions for EPIC-MOS and EPIC-pn, respectively. Single-events EPIC-pn time-averaged spectra were accumulated from circular regions around the apparent centroid of the X-ray source. EPIC-MOS Timing Mode time-averaged spectra

---

[1]The   Release   Note   for   this   SAS   version   is   available   at   the   following   URL: http://xmm2.esac.esa.int/sas/8.0.0/documentation/releasenotes/xmmsas_8.0.0.shtml
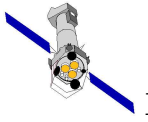
Table 2: Count rates and extraction regions for the observations discussed in this report. The MOS Timing Mode extraction regions are expressed in detector coordinate ranges (extrema included); the imaging modes extraction regions are circles centered around the apparent centroid of the X-ray image.

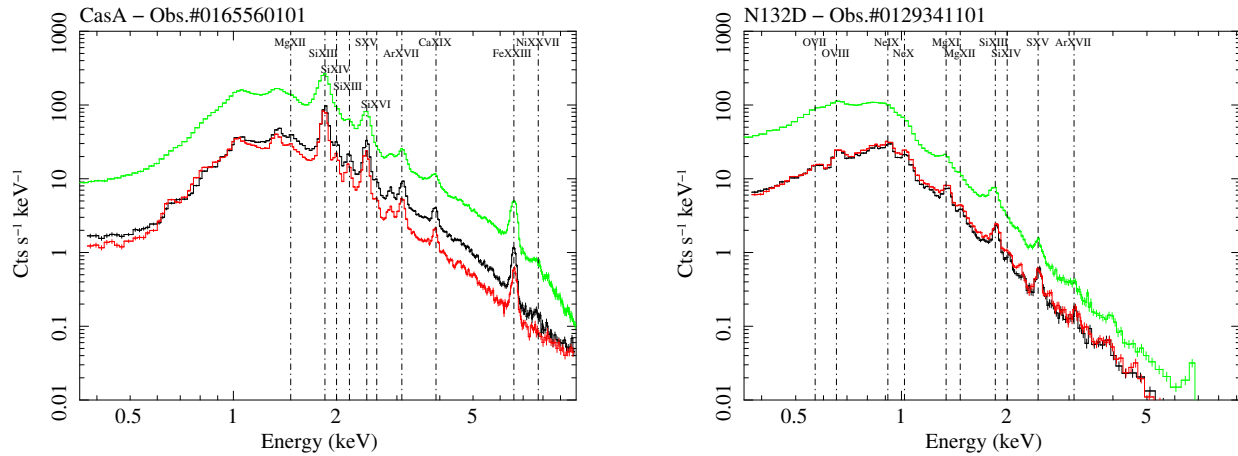| Source | Count rates (s^{-1}) | | | Extraction region ranges | | | radii (") |
	MOS 1[a]	MOS 2[a]	pn/RGS	MOS 1[a] (`RAWX`)	MOS 2[a] (`RAWX`)	pn	MOS[b] (FF/LW)
N132D	18.14 ± 0.04	24.02 ± 0.04	77.59 ± 0.10	270-345	270-345	80	140/120
Cas A	76.01 ± 0.08	53.06 ± 0.07	251.5 ± 0.2	255-324	278-346	240	250/170
AU Mic	...	2.852 ± 0.007	0.612 ± 0.003	...	288-315	...	..

[a]Timing Mode; [b]imaging modes.

Figure 1: The EPIC spectra of Cas A (*left*) and N132D (*right*) discussed in this report. The *dashed lines* indicate the laboratory energies of the transitions used in this report. *Black*: MOS1; *red*: MOS2; *green*: pn.

were accumulated from ranges in `RAWX`. Spectra from the EPIC-MOS exposures in imaging mode were accumulated using the standard combination of single and double events (`PATTERN <= 12`) to maximize the signal-to-noise ratio. In Tab. 2 the size of the spectral extraction regions as well as the count rate in the energy range used for the spectral analysis (see later) is reported.

Spectra have been analyzed in the 0.5-8 keV and 0.5-5 keV energy bands for Cas A and N132D, respectively. This ranges are smaller than the recommended energy range where EPIC-MOS spectra in Timing Mode are nominally calibrated (0.3–10 keV; see Fig. 1). They have been chosen in order to simplify the spectral modeling of these sources, by excluding energy ranges with poor signal-to-noise ratio or no detected emission lines. I modeled the spectra with the combination of two bremsstrahlung continua and as many Gaussian profiles as statistically required by the fit at a confidence level larger than 90% for one interesting parameter according to the F-test. The same confidence level is used to define the statistical errors on the centroid energies in this report. The spectra are shown in Fig. 1, where the *dashed lines* indicate the laboratory energy of the atomic transitions used in this report, according to the ATOMDB database (available at: http://xcx.harvard.edu/atomdb).

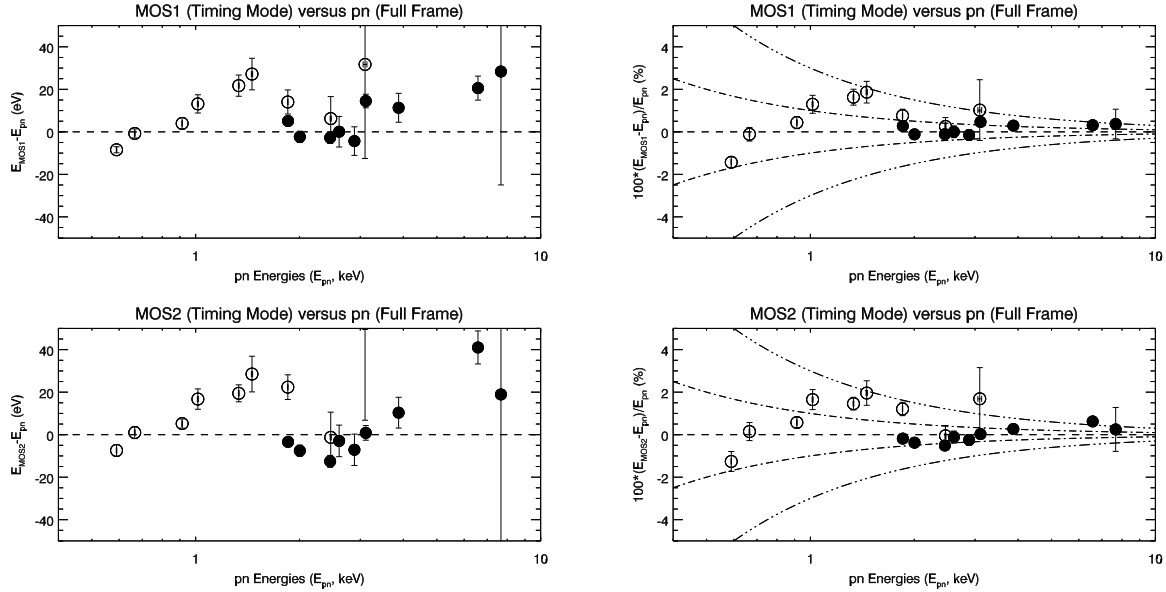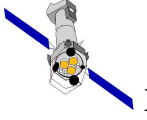The RGS spectra of AU Microscopii were extracted with `rgsproc`. Background spectra were

Figure 2: Difference *left*) and percentage difference (*right*) between the centroid energies measured by the EPIC-MOS cameras (MOS 1: *top*; MOS 2: *bottom*) in Timing Mode and the EPIC-pn (Full Frame) as a function of the centroid energy as measured by the EPIC-pn. *Empty (Filled) circles* correspond to the N132D (Cas A) measurements. The *dashed-dotted* lines mark the ±10 eV and ±30 eV locus around the EPIC-pn energy. Only data points are shown, whose relative statistical error is smaller than 25% on both the pn and the MOS cameras.

accumulated from standard offset positions of the observation field-of-view. The reference sky position for the aspect solution was set equal to the SIMBAD source coordinates: $\alpha_{2000} = 20°45'09".5$, $\delta_{2000} = $ -31^{h}20^{m}27^s. The 0.3–2 keV RGS spectrum was fit with a combination of 1 thermal bremsstrahlung and 17 Gaussian lines (see Appendix A).

3   Results

3.1   EPIC camera cross-calibration

In Fig. 2 I show the discrepancy between the energy measured by the MOS cameras in Timing Mode and simultaneous exposures of the same targets in pn Full Frame mode. These discrepancies are expressed either as the energy difference or as a percentage difference ($\frac{E_{MOS} - E_{pn}}{E_{pn}}$) between the best-fit centroid energies. In Table 1 the mean and standard deviation of the energy differences are reported per camera and observation. At the 1-σ level they are ≤30 eV and ≤20 eV (basically camera-independent) for the N132D and CasA observations, respectively.

Fig. 3 shows the same type of plot as in Fig. 2 for a comparison between MOS exposures in imaging and Timing modes. At the 1-σ level they are ≤30 eV and and ≤20 eV (basically camera-independent) for the N132D and CasA observations, respectively. Interestingly enough, the discrepancy has got *opposite signs* in N132D and CasA.
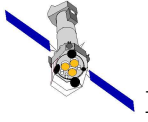
Table 3: Mean and standard deviation (in eV) of the best-fit centroid energy differences measured by EPIC-MOS in Timing and imaging modes, and pn in Full Frame Mode

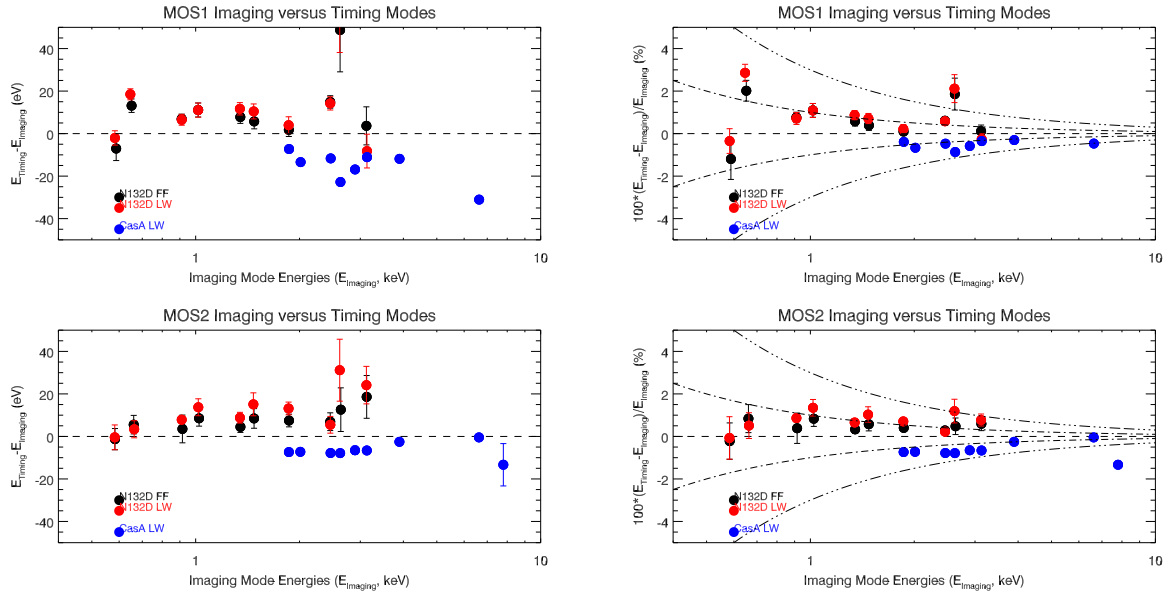| Experiment	N132D	CasA
pn vs. MOS1	12 ± 13	8 ± 12
pn vs. MOS2	15 ± 18	4 ± 17
MOS1 imaging versus Timing modes	11 ± 16	-16 ± 8
MOS2 imaging versus Timing modes	10 ± 8	-7 ± 4

Figure 3: The same plot as in Fig. 2 when MOS exposures in imaging and Timing modes are compared. Different targets and modes are *color coded*.
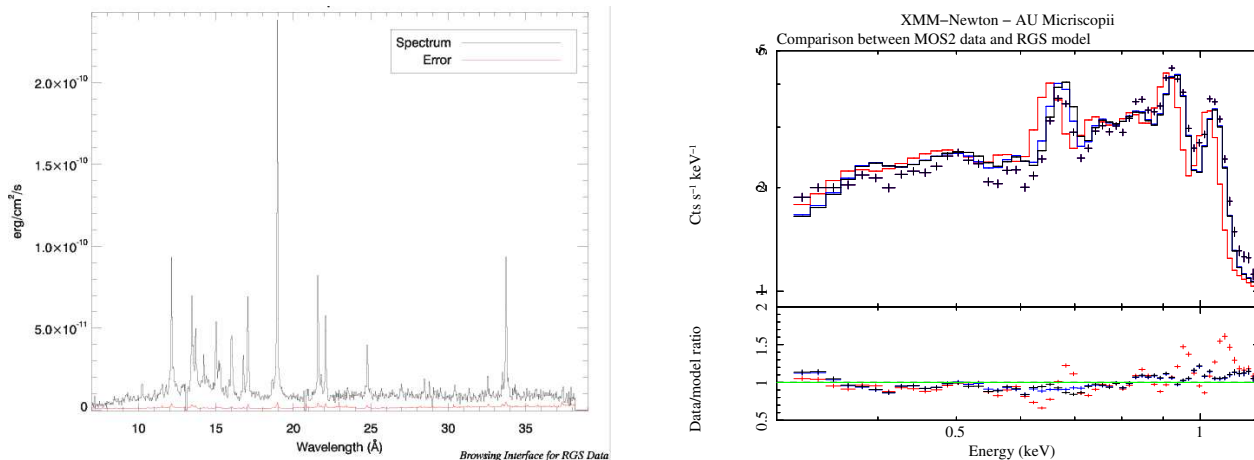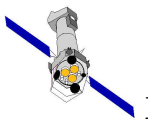
Figure 4: *Left panel*: RGS combined spectra of AU Microscopii (from BiRD; González-Riestra & Rodríguez-Pascual 2008); *Right panel*: MOS 2 spectrum (*upper panel*) and residuals in data/model ratio (*lower panel*) against the best-fit RGS model. The *colors* label the fit with: no gain shifting (*red*); constant offset gain (*black*); or linear gain shift (*blue*).

Table 4: Parameters of the `gain fit` XSPEC command applied to the MOS 2 spectrum of AU Microscopii when the best-fit RGS model is applied.

Offset (eV)	$18.3\pm^{0.7}_{0.3}$	18.8 ± 0.4
Slope	1^{fixed}	$1.00219\pm^{0.00024}_{0.00007}$
MOS 2/RGS 1 normalization	$97.8 \pm 0.5\%$	$98.0 \pm^{0.4}_{0.6} \%$

3.2   Comparison to the RGS model of AU Microscopii

In the *right panel* of Fig. 4 we show the Au Microscopii MOS 2 spectrum in Timing Mode and the data/model ratio when the best-fit RGS model is applied in the 0.3–2 keV energy band. The three colors indicate the nominal spectrum (*red*), and the spectrum to whose response matrix an energy-dependent offset (*black*), and a linear gain correction (*blue*) had been applied. Only an overall normalization factor C was allowed to be free in the fit together with the XSPEC `gain fit` parameters. The improvement from the first to the other two cases is evident. The corresponding `gain fit` parameters are shown in Tab. 4. A nominal shift of $\simeq 19$ eV is required for the optimal alignment between the RGS best-fit model and the energy as measured by the MOS2 camera. Such an offset is mainly driven by the OVIII Ly-α, NeIX He-α and NeX Ly-α emission lines. The observed difference is unaffected by the systematic uncertainties of the RGS wavelength scale (0.7 meV at the OVIII energy).

4   MOS1 exposures in Timing Mode after Rev.#961

A new hot column appeared on MOS 1 CCD1 in Rev.#961 due to a micro-meteoroid event (Guainazzi 2009). The post-impact offset value in MOS1 Timing Mode is far too large for a meaningful correction to be possible. Users are advised to discard the affected column (which in Timing Mode
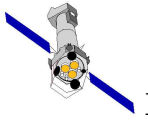
calibrated event lists corresponds to `RAWX=319`) and the adjacent ones from the accumulation of any scientific products. Users are referred to the watchout item at:
`http://xmm2.esac.esa.int/sas/8.0.0/watchout/Evergreen_tips_and_tricks/mos1_timing.shtml`,
which outlines the SASv8.0-compliant procedure to generate a correct effective area file in these cases.

5   Summary and conclusions

This report investigates the accuracy of the energy reconstruction in MOS Timing Mode exposures, by comparing the centroid energies of strong atomic transitions in line-rich SNRs and star spectra against the measurements of the same lines in imaging mode EPIC or RGS exposures. The distribution of the centroid energy differences between measurements in EPIC-MOS Timing Mode and EPIC-MOS or EPIC-pn in imaging mode is $\leq$30 eV ($\leq$ 20 eV) in N132D (CasA). Occasional discrepancies up to 40 eV are observed at the iron line energies in MOS 2, which will deserve further investigation. These results are confirmed by the direct comparison between the EPIC-MOS2 and RGS spectra of AU Microscopii, which requires an energy-independent shift of the MOS2 response by $\simeq$19 eV to be aligned with an RGS-based phenomenological model.

Acknowledgments

Careful reading and detailed comments by M.Santos–LLeo and S.Sembay on an early version of this manuscript greatly improved the quality of the analysis and its presentation.

Appendix A

The model used to phenomenologically fit the RGS spectrum of AU Microscopii is shown below (in compact XSPEC jargon):

```
model  wabs(bremss + 17*gaussian)
     0.00887249      0.001          0          0     100000      1e+06
      0.820706        0.05     0.0001     0.0001        100        200
      0.0105081       0.01          0          0      1e+24      1e+24
         1.021       1e-05          0          0      1e+06      1e+06
             0          -1          0          0         10         20
     0.000516254     1e-06          0          0      1e+24      1e+24
        0.9175       1e-05          0          0      1e+06      1e+06
             0          -1          0          0         10         20
     1.27194e-05     1e-06          0          0      1e+24      1e+24
         0.915       1e-05          0          0      1e+06      1e+06
             0          -1          0          0         10         20
     0.000107945     1e-06          0          0      1e+24      1e+24
         0.922       1e-05          0          0      1e+06      1e+06
             0          -1          0          0         10         20
```
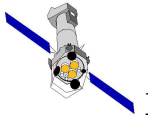
0.000370232	1e-06	0	0	1e+24	1e+24
0.905	1e-05	0	0	1e+06	1e+06
0	-1	0	0	10	20
0.000273348	1e-06	0	0	1e+24	1e+24
0.8725	1e-06	0	0	1e+06	1e+06
0	-1	0	0	10	20
0.000191336	1e-06	0	0	1e+24	1e+24
0.825	1e-05	0	0	1e+06	1e+06
0	-1	0	0	10	20
0.000277688	1e-06	0	0	1e+24	1e+24
0.8175	1e-05	0	0	1e+06	1e+06
0	-1	0	0	10	20
8.71875e-05	1e-06	0	0	1e+24	1e+24
0.812	1e-05	0	0	1e+06	1e+06
0	-1	0	0	10	20
0.000101719	1e-06	0	0	1e+24	1e+24
0.77	1e-05	0	0	1e+06	1e+06
0	-1	0	0	10	20
5.21715e-05	1e-06	0	0	1e+24	1e+24
0.774439	1e-05	0	0	1e+06	1e+06
0	-1	0	0	10	20
0.000242041	1e-06	0	0	1e+24	1e+24
0.738854	1e-05	0	0	1e+06	1e+06
0	-1	0	0	10	20
0.000131671	1e-06	0	0	1e+24	1e+24
0.726698	1e-05	0	0	1e+06	1e+06
0	-1	0	0	10	20
0.00035069	1e-06	0	0	1e+24	1e+24
0.654	1e-05	0	0	1e+06	1e+06
0	-1	0	0	10	10
0.00125406	1e-06	0	0	1e+24	1e+24
0.573998	1e-05	0	0	1e+06	1e+06
0	-1	0	0	10	20
0.000389254	1e-06	0	0	1e+24	1e+24
0.561269	1e-05	0	0	1e+06	1e+06
0	-1	0	0	10	20
0.000287203	1e-06	0	0	1e+24	1e+24
0.367616	1e-05	0	0	1e+06	1e+06
0	-1	0	0	10	20
0.000524661	1e-06	0	0	1e+24	1e+24

References

Bleeker et al., 2001, A&A, 365, 242

Gabriel C., et al., 2003, ASCA, 314, 759

González-Riestra R. & Rodríguez-Pascual P., 2008, Proceedings of the Workshop "Astronomical Spectroscopy and Virtual Observatory", Eds.: M.Guainazzi & P.Osuna, 37

Guainazzi M., 2009, "EPIC Calibration Status Document", XMM-SOC-CAL-TN-0018[2]

---

[2]available at: `http://xmm2.esac.esa.int/docs/documents/CAL-TN-0018.pdf`