XMM-Newton

XMM-Newton Science Analysis System 17.0 scientific validation

XMM-SOC-USR-TN-0029 Issue 1.1

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June 26, 2018

Revision history

Revision number	Date	Revision author	Comments
1.0	May 18 2018	R. Saxton	first draft
1.1	Jun 25 2018	R. Saxton	after revision and comments from co-authors

Contents

1 Introduction

The SAS scientific validation (SV) is performed on a standard set of XMM-Newton observations, which cover all commissioned observational modes, and a number of observations, specially chosen for testing new / special aspects of the data reduction corresponding to the version to be validated. Table 1 lists all the datasets used for the validation of SAS version 17.0. Some of these observations are particularly suitable to test calibration-related items, as specified in the rightmost column of Tab. 1. These datasets are partly intended as a standard reference, which has been and will be used to verify the performances of all SAS versions. However, additional datasets may occasionally be used to test version-specific SAS items. This is the case, for instance, for the datasets discussed in Sect. 2 of this report. Datasets discussed in a given report and not listed in Tab. 1 do not belong to the reference datasets, and are therefore not intended to be discussed in later SAS versions validation reports.

1.1 Methodology

The SV for SAS v17.0 consisted of the following steps:

1. all the datasets listed in Tab. 1 were processed through the SAS 17 based testing Pipeline System (PPS) running at the SOC, and

2. the same datasets were also processed through the SAS reduction meta-tasks: `e[mp]proc`, `om[ifg]chain`, `rgsproc`

3. all the SAS threads were ran as documented, for checking the integrity of the software and the validity of the threads

4. products generated by the above steps were used as a basis for the *interactive SV analysis*. Standard scientific products (images, light curves, spectra, source lists) were generated and analysed as described in Tab. 2. This allowed us to:

   - test the SAS interactive tasks.
   - verify the calibration accuracy obtained with SAS v17.0, and compare it with the expected accuracy on the basis of the calibration status at the time the SV is performed.

5. in addition the whole cross-calibration database has been reduced by standard analysis scripts based on SAS but including also model fitting through Xspec.

Table 1: SV datasets

Instrument	**Mode**	**Object**	**Revolution Obs. ID**	**ID**	**Calibration item**
EPIC MOS	Full Frame	Lockman Hole	544 0147511601	1	Astrometry + source detection
	”	G21.5.09	060 0122700101	2	Effective area
	”	M31	2847 0761970101	2	Extended source
	Small Window (W2)	Mkn 421	165 0099280201	3	
	Large Window (W3)	PKS0558-504	153 0129360201	4	Effective area
	Timing Uncompressed	Her X-1	207 0134120101	5	Timing
EPIC-pn	Full Frame	Lockman Hole	544 0147511601	1	Astrometry
	Full Frame/Small Window	PKS0558-504	153 0129360201	4	Effective area
	Full Frame	M31	2847 0761970101	2	Extended source
	Large Window	AB Dor	185 0133120201	6	
	Small Window	PKS0558-504	084 0125110101	7	Effective area
	Fast Timing	Her X-1	207 0134120101	5	Timing
		Crab	698 0160960201	8	
	Fast Burst	Crab	411 0153750301	9	Timing
		Crab	411 0153750501	10	Timing
	Extended Full Frame	G21.5-0.9	060 0122700101	2	Effective area
	Slew Data		1388 9138800002	18	Slew data processing
	Slew Data		1450 9145000003	19	Slew data processing
RGS	SPEC+Q	PKS0558-504	084 0125110101	7	
”		Mkn 421	165 0099280201	3	Effective area
	”	AB Dor	185 0133120201	6	Wavelength scale
	”	AB Dor	338 0134521301	11	Wavelength scale
	”	AB Dor	462 0134521601	12	Wavelength scale
	”	AB Dor	572 0134522201	13	Wavelength scale
	”	EXO0748-67	044 0119710201	20	Time jumps
	”	MCG-6-30-15	108 0111570201	21	Time jumps
OM	Image Mode	BPM 16274	261 0125320701	14	Photometry
	Fast Mode	X1822-371	228 0111230101	15	
	FF Low Resolution	BPM 16274	261 0125320701	14	Astrometry
	Optical grism	Hz2	503 0125910901	16	Wavelength scale & flux calibration

1.2 Calibration data to be used

The calibration data to be used for this version was derived from the full public calibration constituents as of 8 Feb 2018, plus the following components which at this date were not yet public:

- OM_BADPIX_0006.CCF (made public with the SAS 17 release, since it needs `ommodmap` version 2.5 which will be released with SAS 17),

2 New and updated in SAS 17.0

Version 17.0 is a main yearly release of the SAS, containing new capabilities, including the task `xmmextractor` and a python wrapper for the graphics. Below we detail the changes which specifically need testing.

2.1 New in SAS 17.0: xmmextractor

This is an overarching task which creates images, spectra and light curves from the X-ray and optical cameras after applying a full standard analysis on the event data.
Validation should show that correct products are produced for many different datasets, using a full range of observing modes. The graphical user interface (GUI) introduces Python into the SAS for the first time. This aspect should be tested on a variety of platforms to ensure compatibility of third-party libraries and general robustness against system differences.

2.2 New in SAS 17.0: CTI correction for EPIC-pn events based upon the number of discarded lines

It has been noticed that the CTI experienced by an event depends on the recent background which a given detector pixel has been exposed to. The background appears to be well approximated by the 'number of discarded lines' counter, which is available as a function of time in the housekeeping data and can therefore be used as a proxy. Functionality to correct the amplitude of each event by the local discarded line level has been added into the SAS. It has led to a change in the coefficients of the long-term CTI correction which previously modelled the evolution of the CTI over the course of the mission, as a polynomial.
Tests should ensure that the new algorithm in SAS 17 provides equally good or better energy reconstruction than achieved in SAS 16 for a set of ODFs which sample a range of mission epochs, observation modes and background levels.
Relevant parameters in `epchain` are "backgroundtres" and "backgroundtbin". These should also be in `epproc` if finally adopted.

2.3 Updated in SAS 17.0: backscale values for EPIC spectra

The pixel resolution has been increased to provide better accuracy. Check that the values are slightly different ($< \pm 10\%$) from SAS 16 values for imaging and FAST mode data. Also ensure that the execution time is acceptable for realistic scenarios, including large extended sources.

2.4 New in SAS 17.0: rgsFrameJumpFix

Problems in the generation of RGS lightcurves with rgslccorr have been recently detected. These problems have been tracked down to corrupted AUX files, showing frame jumps of the order of

2^{16}. This leads to the number of entries in the STDGTI and EXPOSURE extensions in the final event list being different and, as a consequence of this, the lightcurve produced by rgslccorr is incorrect. In addition, in some cases the exposure time of the extracted spectrum is wrong.
The task rgsframejumpfix, new in SASv17, detects and corrects these problems. This is a SOC-only task, not included in the public distribution. It has to be run at the time of the generation of the ODF to check whether the RGS AUX files are affected by this problem. It can be also run to fix old ODFs.

2.5 New in SAS 17.0: x/y detector maps in arfgen

An X/Y image may now be used to define the spatial distribution of a source within the arfgen task. This can be from any of the EPIC cameras. It should be checked that this produces results consistent with those obtained by using a detector pixel image. This map can also optionally be used to correct for missing data due to chip gaps, bad columns and bad pixels with the command:

```
arfgen spectrumset=myspec.ds extendedsource=yes detmaptype=dataset
detmaparray=myxyimage.ds badpixmaptype=dataset
```

2.6 Updated in SAS 17.0: psfgen

We receive frequent helpdesk questions about the usage and output of the psfgen task due to its non-intuitive interface and inadequate documentation. The task and documentation has been rewritten to solve these problems, although the output remains essentially the same. The task should be tested to ensure that the produced PSF images have not changed significantly from the SAS 16 output for the three EPIC cameras and various off-axis and rotation angles. The interface and documentation should be assessed for user-friendliness.

2.7 Updated in SAS 17.0: eslewchain

Within the pipeline, test that the slew chain executes correctly when images with no events are created and when source lists with no sources are created. Also check that png files are successfully created in problem cases.

2.8 Updated in SAS 17.0: multi-pointing mode

There has been a problem with transformations between sky and detector coordinates in multi-pointing mode observations. This should be solved by running arfgen with the option *useodfatt=yes*. Check that the flux of RX J1856.5-3754, returned by xspec, is consistent between the four pointings contained in observation 0412601501.

2.9 Updated in SAS 17.0: source searching

Some changes to eboxdetect have been applied in this release. Checks should be made that source searches present compatible results with those obtained in SAS 16.1.

3 Validation results

3.1 Validation schedule

This SAS version should be released in two Linux OS 64 versions (Red Hat Enterprise and Ubuntu LTS) as well as one MacOs version (Sierra), to cover a broad band of kernels. One Virtual machine will be made available for 64 bit OSs.
The schedule for the validation foresees a total of around 6 weeks for performing the different tasks (for the period from going into release track mode to final release). These are the projected milestones:

- SAS into release track mode
- SAS builds on different platforms
- SAS 17 binaries (at least 1 platform)
- Processing of all the standard datasets
- Installation of SAS 17 binary in XCal grid
- Communication to validators about success and data location
- Preparation of a SAS 17 based PPS test version
- Processing of standard datasets by testing pipeline
- Processing of standard datasets by all binaries + cross-checks
- Processing of XCal archive
- First I/A analysis of standard data
- Evaluation of XCal
- Screening of PPS processed standard datasets
- Integrity checks running all the existing SAS threads
- Dedicated analysis (see section 2)
    1. `XMMextractor` evaluation

Table 2: Comparison elements

Calibration Item	**Test products**	**Test items**
Astrometry + source detection	Source lists	Nr. of sources, positions, fluxes
Effective Area	Spectra + Light curves	Model results, harness ratios
Timing	Light curves + Fourier transforms	Periodicities
Wavelength scale	Spectra + Light curves	Line positions and strengths
Photometry	Source lists	Fluxes

2. Discarded Lines tests
3. Backscale values for Timing mode
4. `rgsFrameJumpFix` tests
5. x/y detector maps in arfgen tests
6. `psfgen` tests
7. `eslewchain` tests
8. multi-pointing mode flux validation
9. source search cross-check

- Summary reports
- SAS VM produced
- Processing of all standard sets with VM
- Final SV individual reports
- Release notes + SAS 17 web pages contents ready + XMM Newsletter text
- SAS 17 distribution tar files ready
- SAS 17 release
- Final SV Report compilation

3.2 Processing of standard datasets

All the datasets listed in Tab. 1 have been processed with the full data reduction scripts used for validation without any failure, on the 3 main building platforms (RHEL 6.8, Ubuntu 16.04LTS, macOS Sierra). The runs took ~ 17 hours of processing time on Linux and $\sim 6 - 8$ hours on macOS. This processing time includes elapsed time of pure CPU processing and time spent on I/O from/to local disk.

3.2.1 EPIC data - standard set

The standard EPIC datasets were processed without any obvious errors being produced. Results were compared with the processing from SAS 16 and were found to be consistent.

3.2.2 RGS data - standard dataset

The standard set of validation data processed with the SASv17.0 build have been examined. Output products of rgsproc have been compared with the result of processing with previous versions of SAS. No significant differences have been found.

3.2.3 SAS OM data processing

There are no major changes in the OM tasks in this version of SAS although it is worth mentioning a change in the task **ommodmap** triggered by a new version of the OM_BADPIX CCF. We have verified the results of the new SAS in the standard validation dataset. The results for imaging, fast mode and grisms spectroscopy are correct.
In addition to that, we have processed with **omichain** and also with **omfchain** all observations of our three standard stars, GD 153, Hz 2 and BPM 16274. All results are satisfactory.
Some little bugs and caveats that were reported in previous versions of SAS remain unsolved (e.g. in Fast Mode processing or in the interactive tasks **omsource** and **omgsource** in SAS 15). The reader is thus referred to previous Science Validation Reports for more detailed comments or descriptions in relation with OM.

3.2.4 Test pipeline checks

A Pipeline based on SAS v17 was used to process a set of 70 observations (the standard validation set + the last 10 XMM revolutions). All of the jobs finished successfully with no errors found.

3.2.5 XCal data

The new SAS version SASv17.0 was compared with its previous version SASv16.0 by performing spectral extractions of 320 individual exposures of 51 targets of various source types throughout all the epochs of the mission that are included in the XMM-Newton SOC cross-calibration archive

- 198 exposures of on-axis point targets of various source types, mainly with continuum dominated spectra, from isolated neutron stars to AGN.
- 86 exposures of 2 different thermal supernova remnants
- 12 exposures of 4 different galaxy clusters
- 24 off-axis point sources (AGN).

All comparison results of the spectral extractions using the two different versions of the SAS show conformity according to the calibration status and it's software support of the corresponding version.

3.3 Processing with SAS built on a different flavour than the one used - Compatibility

The two Linux versions (RedHat EL 6.8 and Ubuntu 16.04) have been isuccessfully used on a variety of different systems, including CentOs 7.3, to check for compatibility issues. SAS built on MacOs Sierra was executed on Macs running the El Capitan and High Sierra operating systems without problems.

3.4 Dedicated analysis

3.4.1 EPIC data - G21.5-0.9

The non-thermal SNR G21.5-0.9 has been used as one of the standard targets for the validation of the EPIC effective area calibration. Additionally, this source has proven useful in multi-

mission cross-calibration studies (Tsujimoto et al. 2011). Its spectrum can be well modelled by a simple power-law combined with a photoelectric absorption.
In observation 0122700101, G21.5-0.9 was observed with MOS in Full Frame mode and PN in Extended Full Frame Mode (all using Medium Filter) for 30 ks. MOS and PN source spectra were extracted from a circular region (∼ 2.5 arcmin radius) around the SNR, and spatially filtered through their common exposure mask. MOS background spectra were obtained from annular regions around the source, whereas PN background was obtained from neighbouring source free regions. EPIC data were reduced with SASv17.0 and spectra were extracted with standard event pattern selection.
The results of the comparison of PN and MOS are summarised in Fig. 1, and are essentially in agreement with the previous SAS science validation study. This is as expected, as no significant changes in energy scale calibration have been introduced in the meantime.

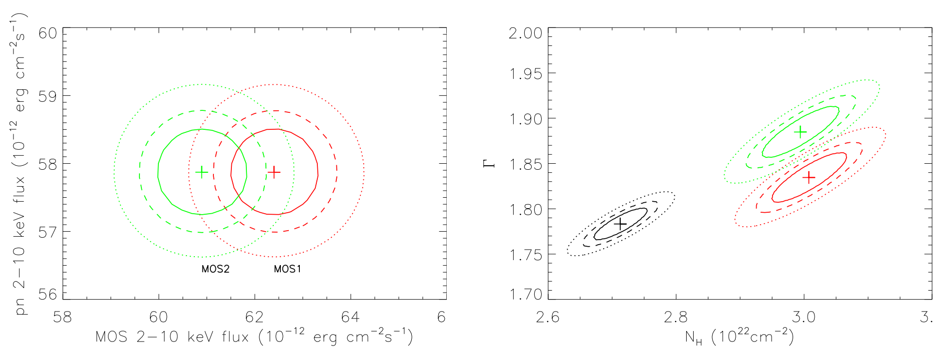

Figure 1: Comparison of PN versus MOS spectral fits of G21.5-0.9. Spectra based on data reduced with SASv17.0, using standard pattern selection. *Left panel*: the 2-10 keV flux confidence contours for PN versus MOS1 (red) and MOS2 (green). *Right panel*: column density versus photon index confidence contours for PN (black), MOS1 (red), MOS2 (green). Levels shown are at 68%, 90% and 99% confidence.

3.4.2 EPIC Data - PKS 0558-504

PKS 0558-504 is a well studied radio loud Narrow Line Seyfert 1 galaxy (e.g. Siebert et al. 1999), and has been observed by *XMM-Newton* as calibration target. Its 2-10 keV spectrum is characterised by a spectral slope $\Gamma \sim 2.2$, and the 0.2-2 keV emission is dominated by a large and featureless soft excess.
EPIC spectra of ObsIds 0125110101 and 0129360201 are compared as part of this science validation. In the exposures compared here, PN was operated in Small Window Mode, and both MOS instruments in Large Window Mode. Data were reduced with SAS 16.0 (using the respective latest calibration files), and resulting spectra were fit in the 0.3–10 keV band with a model consisting of a power-law and bremsstrahlung component with an ISM absorbtion model (Papadakis et al. 2010). As the MOS data are subject to pile-up the spectra were extracted from annular regions with core exclusion radii of 10".
The best fit results are summarised in Tables 3 and 4. The main differences between instruments are due to the imperfect relative effective area calibration, resulting in fluxes which are formally not consistent across all three instruments.

Table 3: Comparison of MOS and PN spectral fits to PKS 0558-504 (ObsId 0125110101) with a power-law plus bremsstrahlung model.

Instrument	kT keV	Γ	Flux 10^{-11} erg cm^{-2} s^{-1} (0.3–2.0 keV)	(2.0–10.0 keV)
MOS1	$0.25^{+0.03}_{-0.03}$	$2.21^{+0.17}_{-0.23}$	$2.13^{+0.02}_{-0.02}$	$0.91^{+0.05}_{-0.06}$
MOS2	$0.34^{+0.06}_{-0.08}$	$2.07^{+0.18}_{-0.18}$	$2.29^{+0.02}_{-0.02}$	$0.94^{+0.05}_{-0.05}$
PN	$0.28^{+0.03}_{-0.03}$	$2.23^{+0.06}_{-0.06}$	$2.48^{+0.03}_{-0.03}$	$1.07^{+0.07}_{-0.06}$

Table 4: Comparison of MOS and PN spectral fits to PKS 0558-504 (ObsId 0129360201) with a power-law plus bremsstrahlung model.

Instrument	kT keV	Γ	Flux 10^{-11} erg cm^{-2} s^{-1} (0.3–2.0 keV)	(2.0–10.0 keV)
MOS1	$0.40^{+0.09}_{-0.08}$	$1.96^{+0.18}_{-0.15}$	$2.53^{+0.02}_{-0.02}$	$1.32^{+0.06}_{-0.06}$
MOS2	$0.25^{+0.06}_{-0.05}$	$2.24^{+0.11}_{-0.10}$	$2.47^{+0.02}_{-0.02}$	$1.18^{+0.05}_{-0.05}$
PN	$0.35^{+0.03}_{-0.03}$	$2.12^{+0.04}_{-0.05}$	$2.44^{+0.01}_{-0.01}$	$1.18^{+0.02}_{-0.02}$

3.4.3 Standard tests of `esas`

The full thread for `esas` images extraction has been run on the observation 0097820101 of the Abel 1795 galaxy cluster for EPIC-pn and MOS data. In detail the following tasks have been run:

- pn-filter, mos-filter
- cheese prefixm='1S003 2S004' prefixp=S005 scale=0.4 rate=0.2 dist=40.0 clobber=0 elow=300 ehigh=10000 mlmin=15.0
- pn-spectra prefix=S005 caldb=/ccf/pub/extras/esas_caldb mask=1 elow=400 ehigh=2000 quad1=1 quad2=1 quad3=1 quad4=1
- mos-spectra prefix=1S003 caldb=/ccf/pub/extras/esas_caldb region=regm1.txt mask=1 elow=400 ehigh=2000 ccd1=1 ccd2=1 ccd3=1 ccd4=1 ccd5=0 ccd6=1 ccd7=1
- pn_back prefix=S005 caldb=/ccf/pub/extras/esas_caldb diag=0 elow=400 ehigh=2000 quad1=1 quad2=1 quad3=1 quad4=1
- mos_back prefix=1S003 caldb=/ccf/pub/extras/esas_caldb diag=0 elow=400 ehigh=2000 ccd1=0 ccd2=1 ccd3=1 ccd4=1 ccd5=0 ccd6=1 ccd7=0
- proton prefix=S005 caldb=/ccf/pub/extras/esas_caldb specname=pnS005-obj.pi ccd1=1 ccd2=1 ccd3=1 ccd4=1 elow=400 ehigh=2000 spectrumcontrol=1 pindex=0.972080 pnorm=0.131099

- proton prefix=1S003 caldb=/ccf/pub/extras/esas_caldb specname=mos1S003-obj.pi ccd1=0 ccd2=1 ccd3=1 ccd4=1 ccd5=0 ccd6=0 ccd7=0 elow=400 ehigh=2000 spectrumcontrol=1 pindex=0.972080 pnorm=0.131099

- rot_det_sky mode=1 prefix=S005 elow=400 ehigh=2000 detx=-1079.810798 dety=1482.314823 skyx=450.91 skyy=450.91 maskfile=1 clobber=1

- omb caldb=/ccf/pub/extras/esas_caldb withpartcontrol=1 withsoftcontrol=1 withswcxcontrol=0 elowlist=400 ehighlist=2000 mask=1 prefixlist="1S003 2S004 S005"

- adapt smoothingcounts=50 detector=0 thresholdmasking=0.02 binning=2 elow=400 ehigh=2000 withmaskcontrol=no withpartcontrol=yes withsoftcontrol=yes withswcxcontrol=no

The above list of tasks was run successfully on a 64 bit machine to produce a mosaic image of the three instruments with point sources removed (also smooth version of image produced). For simplicity, only the energy range elow=400 ehigh=2000 was used. Along the way the following problems were found:
- `cheese` failed because only EPIC-pn was used within edetect_chain. This was fixed.
- `pn_back` failed because of an error in the configuration file. Fixed in version 0.10.5.

The masks produced by cheese correctly exclude sources proportional to the source strength given the following parameters:
cheese prefixm='1S003 2S004' prefixp=S005 verb=0 scale=0.5 rate=1.0
dist=40.0 clobber=1 elow=300 ehigh=10000

3.4.4 Repeatability of OM filter photometry

Several spectrophotometric standard stars are observed repeatedly with OM in order to establish and monitor the photometric and flux calibrations. These are the white dwarfs GD 153, HZ 2 and BPM 16274.
All existing data of these stars have been reprocessed using SAS 17. The results are presented in Table 5. For comparison we also give these results obtained with SAS 16 (see Table 6). Quoted errors are the standard deviation of the mean given as a percentage.
We see that after all corrections are applied, the count rates of these stars obtained from all observations taken during the life of OM are constant to within 3 %.

Table 5: Standard stars processed with SAS 17.0 : average count rates of several observations

star	N_obs	UVW2	UVM2	UVW1	U	B	V
GD153	15	83.29	161.89	330.03	420.25	283.69	71.57
error (%)		1.5	1.5	1.0	1.4	1.0	2.4
HZ2	18	23.81	48.27	111.78	168.71	148.83	43.84
error (%)		2.1	1.3	1.3	0.9	0.8	3.0
BPM16274	32	14.75	30.34	72.96	112.62	107.81	33.04
error (%)		1.8	1.2	1.0	0.8	0.9	2.4

Table 6: Standard stars processed with SAS 16.0 : average count rates of several observations

star	N_obs	UVW2	UVM2	UVW1	U	B	V
GD153	14	83.12	161.78	329.49	420.18	283.45	71.35
error (%)		1.4	1.5	0.8	1.4	1.0	2.1
HZ2	17	23.76	48.27	111.73	168.84	148.83	43.73
error (%)		2.0	1.3	1.3	0.9	0.8	2.9
BPM16274	32	14.73	30.34	72.92	112.68	107.77	32.95
error (%)		1.7	1.2	1.0	0.8	0.8	2.2

4 New and updated in SAS17 - Validation

4.1 New in SAS 17.0: xmmextractor

The GUI version of the task `xmmextractor` was run on the odf 0303720201 for the EPIC-pn, MOS and RGS cameras. Using the task defaults results in the correct production of spectra and light curves for the central source, i.e. the target of the observation. Some robustness issues were found but are not considered to be showstoppers. One important issue was found whereby the xmmextractorGUI task does not work for users who attach to a Mac machine using `ssh`. A watchout item has been raised to warn users of this feature.

4.2 CTI correction for EPIC-pn events based upon the number of discarded lines

Two CalClosed observations with large variation of discarded line rate over the exposure were identified. When processed with SAS 16.0.1, the energy of the Mn-Kα line is overcorrected by 16 and 25 eV for the two observations. A gain correction based on time-resolved discarded lines was turned on in the SAS 17.0 software with a time resolution of 5, 100, 10000 amd 50000 seconds. All of the binnings yield better results than the current SAS. The integration of 5 and 100 seconds gives the best result with the larger times producing a small undercorrection for these two cases (Fig. 2).
The improved energy correction did not produce an appreciable narrowing of the line widths.
For the purposes of the SAS release, it was tested that, with the current CCF that has the correction set to zero, the same results are obtained with SAS 17 as SAS 16. This CCF will be updated soon after the SAS 17 release when the optimal correction has been established.

4.3 Updated in SAS 17.0: backscale values for EPIC spectra

In SAS 16 a problem was noted with the BACKSCAL value returned by the `backscale` task and the fluxes returned by xspec when a systematic analysis, varying the size of the extraction region, was performed on EPIC-pn Timing mode data. The analysis was repeated for SAS 17, on the blazar PKS2155-304 (Fig. 3). The area of the extraction region should be an integral multiple of the size of an individual column, however, for SAS 16 (red curve in Fig. 3 left), there are deviations of a few percent when the region consists of small numbers of columns. This error has disappeared with SAS 17 (blue curve). The flux ratio for three photon energy ranges, as a function of the number of columns used to extract the spectrum, is shown in Fig. 3 (right).

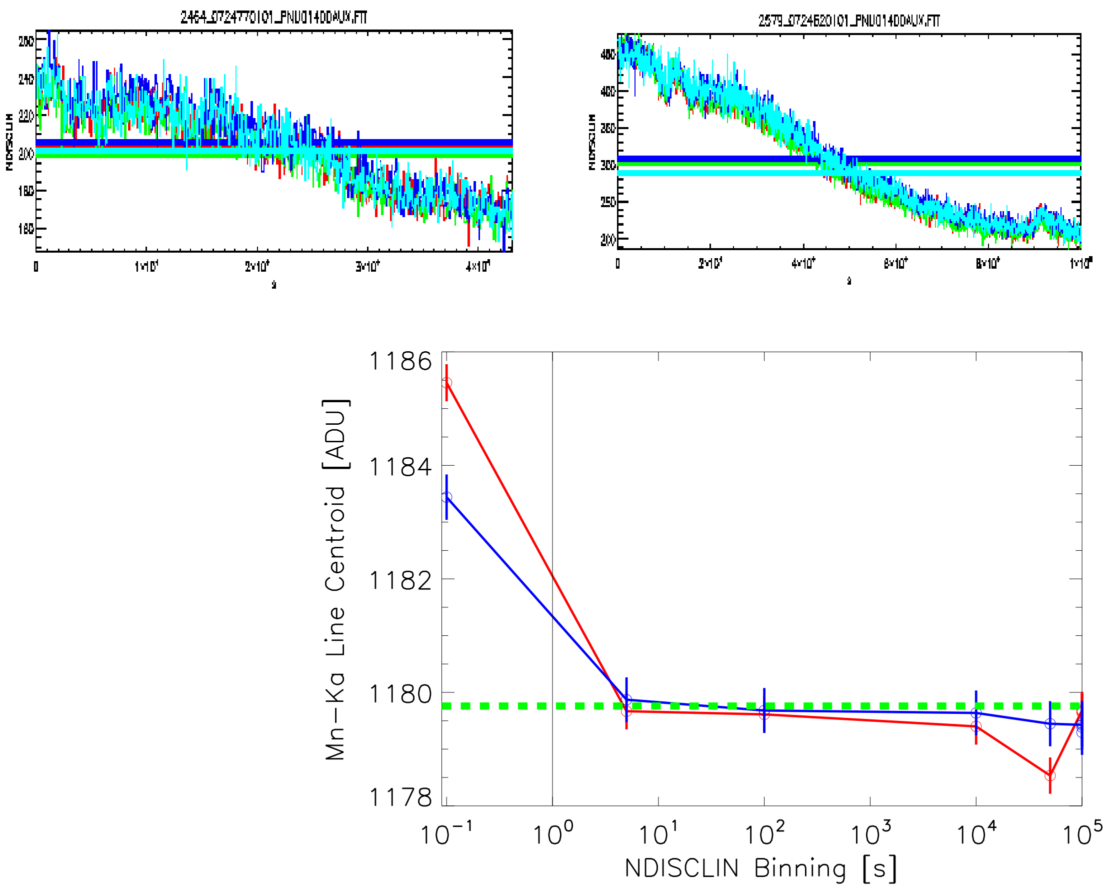

Figure 2: Top: The number of discarded lines plotted against time for observation 0724770101, revolution 2464 (left) and observation 0724520101, revolution 2579 (right). Bottom: The measured energy of the Mn K_{α} calibration line compared with the nominal value (green dashed line), plotted against the discarded line integration time for observations 0724770101 (blue) and 0724520101 (red). The first point corresponds to the correction without any discarded line correction, i.e. the scheme used in SAS v16.

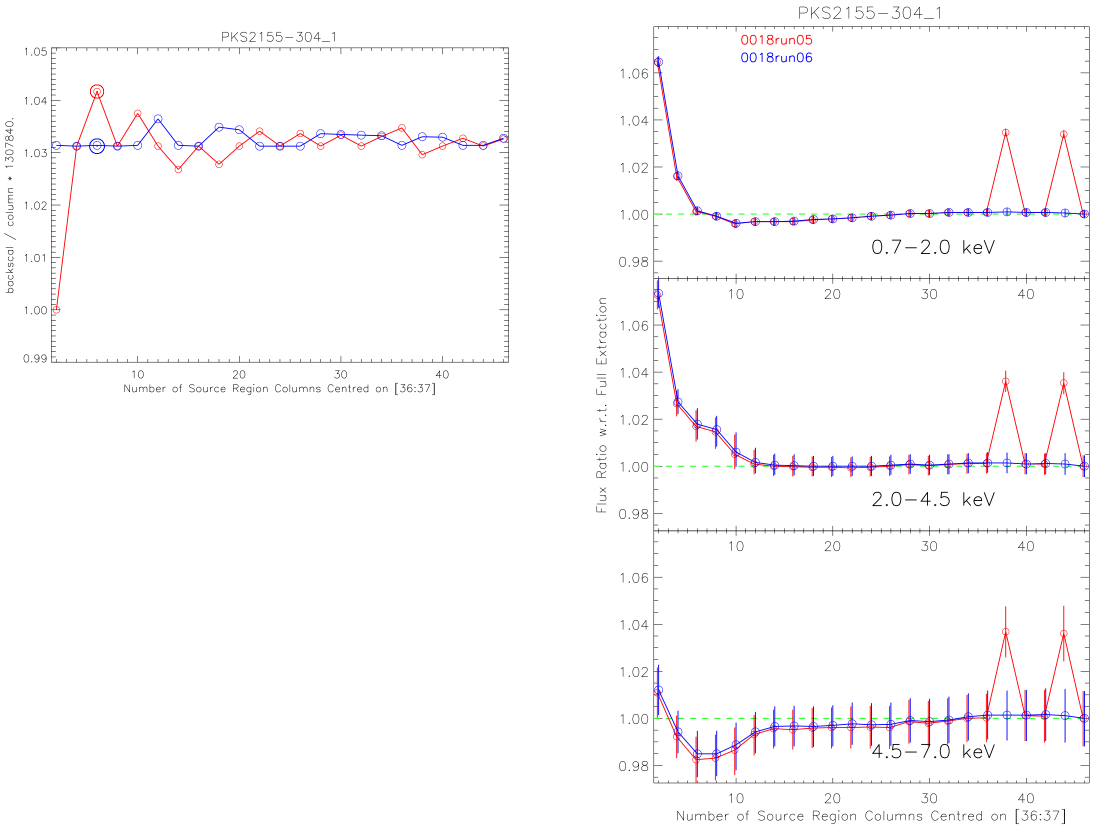

Figure 3: Left: Area of the source extraction region for a Timing mode observation as calculated by `backscale` against the number of columns used in the extraction (SAS 16.0.1: red curve; SAS 17: blue curve). Right: ratio of returned flux for source extractions of increasing number of columns, compared with that obtained from the full extraction area, for energy ranges of 0.7–2, 2–4.5 and 4.5–7 keV.

The results are similar for SAS 16 and SAS 17 apart from two points in the SAS 16 curve which show a deviation of $\sim 4\%$. This problem is not present in the SAS 17 reprocessing.

4.4 New in SAS 17.0: rgsFrameJumpFix

The task, `rgsFrameJumpFix`, has been tested on 256 exposures with corrupted AUX files (150 RGS1, 106 RGS2). The ODFs have been processed with SASv16, and with SASv17 after correcting the AUX and SPE files with rgsframejumpfix, generating in both cases lightcurves and count spectra.

4.4.1 Frame Jumps

Frame jumps were corrected in all but four (1.5%) of the 256 cases studied. In two of these four cases the AUX files show entries with a negative value of EOSCOARS, see Table 7.

4.4.2 Light Curves

RGS light curves have been generated with rgslccorr after the correction for frame jumps. The improvement is clearly seen, in particular for those cases in which there were multiple frame jumps in the AUX file. A few examples are shown in Fig. 4.

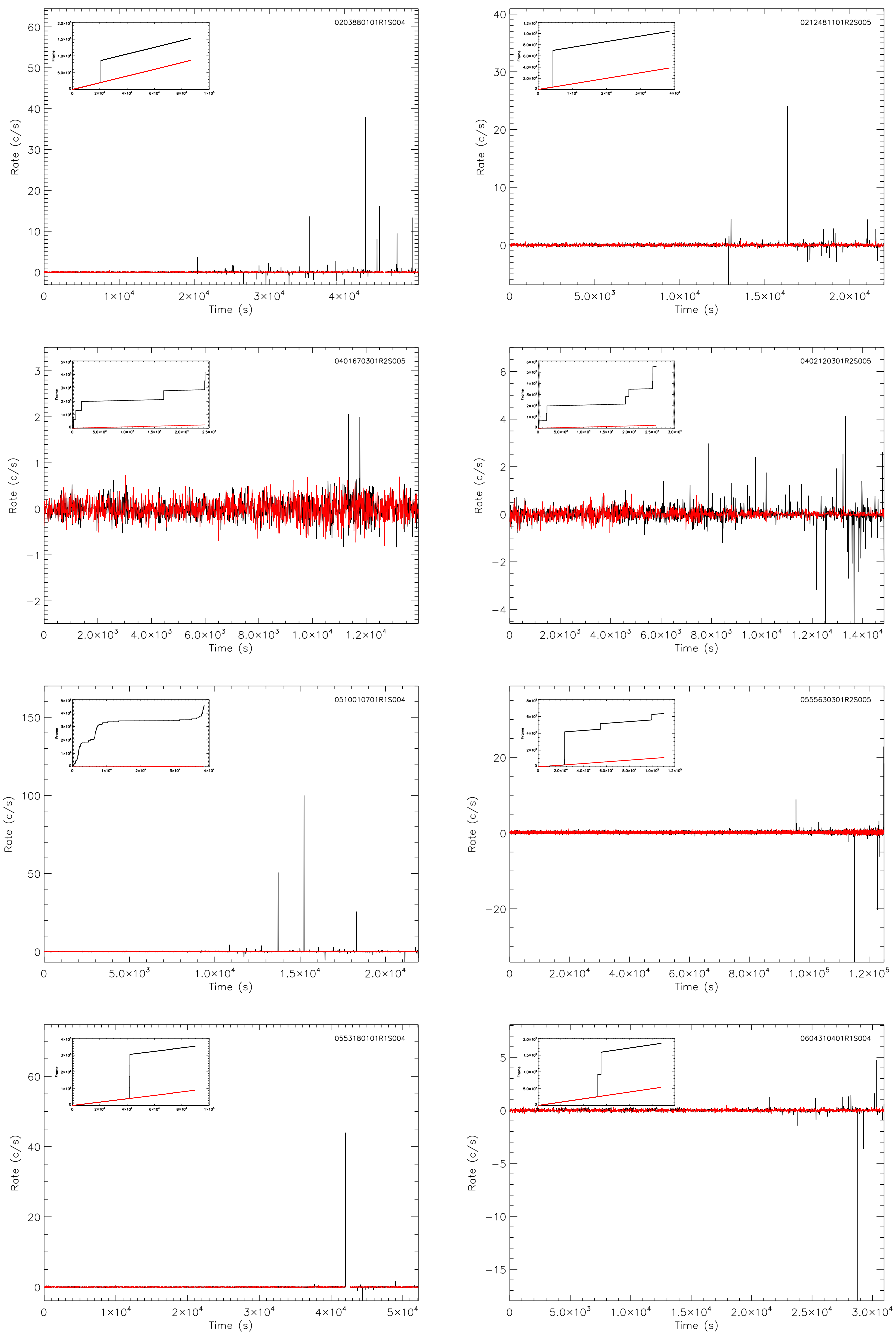

Figure 4: Examples of light curves corrected for frame jumps. Shown in black are data processed with SASv16, in red with SASv17 after correction with `rgsframejumpfix`. The inset shows the frame counter.

Table 7: Exposures showing differences in exposure time larger than 1%

expid	T_{SASv16}	T_{SASv17}	difference (s) [%]	comment
0723801601R1S004	98488	55065240	4966752 [-55810.1]	not corrected
0780760101R1S004	70833	5422571	5351737 [-7555.4]	not corrected, negative EOSCOARS
0780760101R2S005	432235	18	432217 [100.0]	not corrected, negative EOSCOARS
0803950301R2S005	24534	11674	12859 [52.4]	not corrected
0410180301R1S004	9838	14035	-4196 [-42.7]	
0611183201R2S008	7233	7711	-478 [-6.6]	
0153450101R1S004	65936	65101	835 [1.3]	
0153450101R2S005	64855	64074	780 [1.2]	
0111570201R1S004	65519	64789	730 [1.1]	
0510010101R1S004	5255	5196	58 [1.1]	
0140950601R1S004	14727	14585	141 [1.0]	
0140950601R2S007	14731	14585	145 [1.0]	

Table 8: Results obtained running arfgen on a MOS-1 spectrum of 1E0102-72.2

Detector Map image	ARF at 1 keV	Bad pixel fraction
	cm^2	%
MOS det coords	302.8	2.9
MOS sky coords	295.6	5.1
PN det coords	266.9	14.3
PN sky coords	270.1	13.3
flat	273.8	12.0

4.4.3 Exposure Times

In 217 out of 256 cases the difference in the exposures times of the extracted spectra (EXPOSURE keyword) is less than 10s. In 230 cases this difference represents less than 0.5% of the exposure time. Table 7 lists the cases in which exposure times differ by more than 1%. Those with the largest difference are the four cases in which the fix with rgsframejumpfix did not work correctly.

4.5 New in SAS 17.0: x/y detector maps in arfgen

A spectrum was extracted from a MOS-1 observation (0791581101) of the SNR 1E0102-72.2 using a circle of radius 750 sky pixels, which includes a bad column (Fig. 5). An ARF was generated by the `arfgen` task using various detector maps (see Tab. 8). Detector pixel and sky pixel images from both MOS-1 and EPIC-pn were used for comparison. When the MOS-1 images are used, the fraction of area which is lost to bad pixels is lower than that recorded when EPIC-pn images are used for the detector map. This is because in the MOS-1 images the events in the bad column are flagged out and so the weighting given to this area is low. In the pn images they are weighted correctly. The difference in ARF between the EPIC-pn detector and sky coordinate images is fairly small, showing that both can be used. The *flat* detector map reproduces the SAS 16 behaviour and gives a slightly lower bad pixel fraction than using the SNR flux from the EPIC-pn images.

4.6 Updated in SAS 17.0: psfgen

The task command interface and user documentation were checked and found to be clearer than before. All examples from the `psfgen` user documentation were run successfully and produced

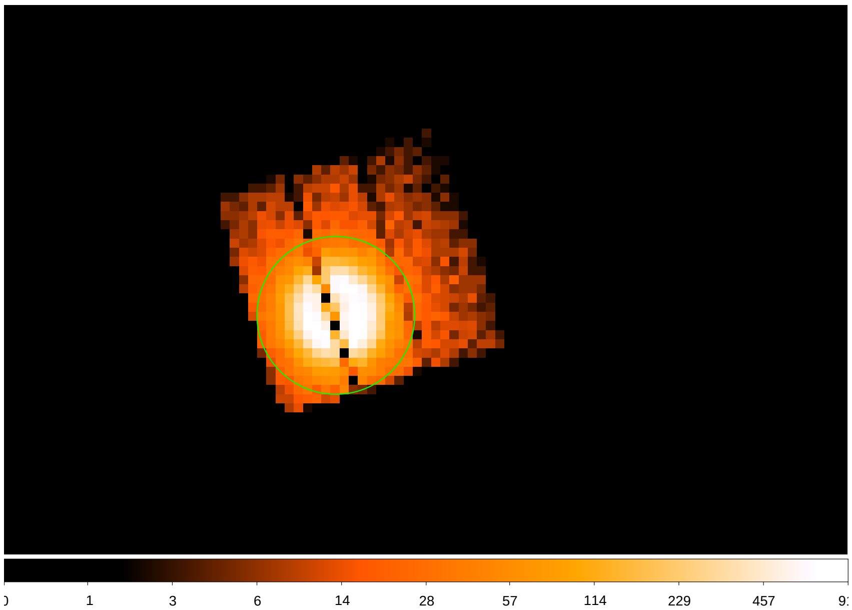

Figure 5: MOS-1 sky coordinate image of 1E0102-72.2. The green circle indicates the region used to extract the MOS-1 spectrum which contains a bad column.

output images that appeared to be correct. Examples are shown in Fig. 6.

4.7 Updated in SAS 17.0: eslewchain

The pipeline, updated with the current SAS 17 slew processing tasks, was run on a representative set of slews. All slews processed successfully apart from the following errors:

```
9313500003   088607   mv error
9317300003   088609   # ** eboxdetect: error (EmptyImage), Input image is empty
9317600002   088612   # ** eboxdetect: error (EmptyImage), Input image is empty
9319200003   088617   # ** eboxdetect: error (EmptyImage), Input image is empty
9322200007   088622   mv error, 'Source file not defined'
9323700002   088625   # ** eboxdetect: error (EmptyImage), Input image is empty
9324200002   088626   # ** eboxdetect: error (EmptyImage), Input image is empty
9325400005   088627   # ** eboxdetect: error (EmptyImage), Input image is empty
9328400005   088631   mv error, 'Source file not defined'
9331800003   088632   # ** eboxdetect: error (EmptyImage), Input image is empty
9332900002   088634   # ** eboxdetect: error (EmptyImage), Input image is empty
9333100002   088635   # ** eboxdetect: error (EmptyImage), Input image is empty
9334300004   088637   # ** eboxdetect: error (EmptyImage), Input image is empty
9335600004   088638   # ** eboxdetect: error (EmptyImage), Input image is empty
```

New versions of tasks, eslewchain v1.17.1, eboxdetect v4.28.2 and a modified pipeline were produced. Retests showed that all slews are now successfully processed.

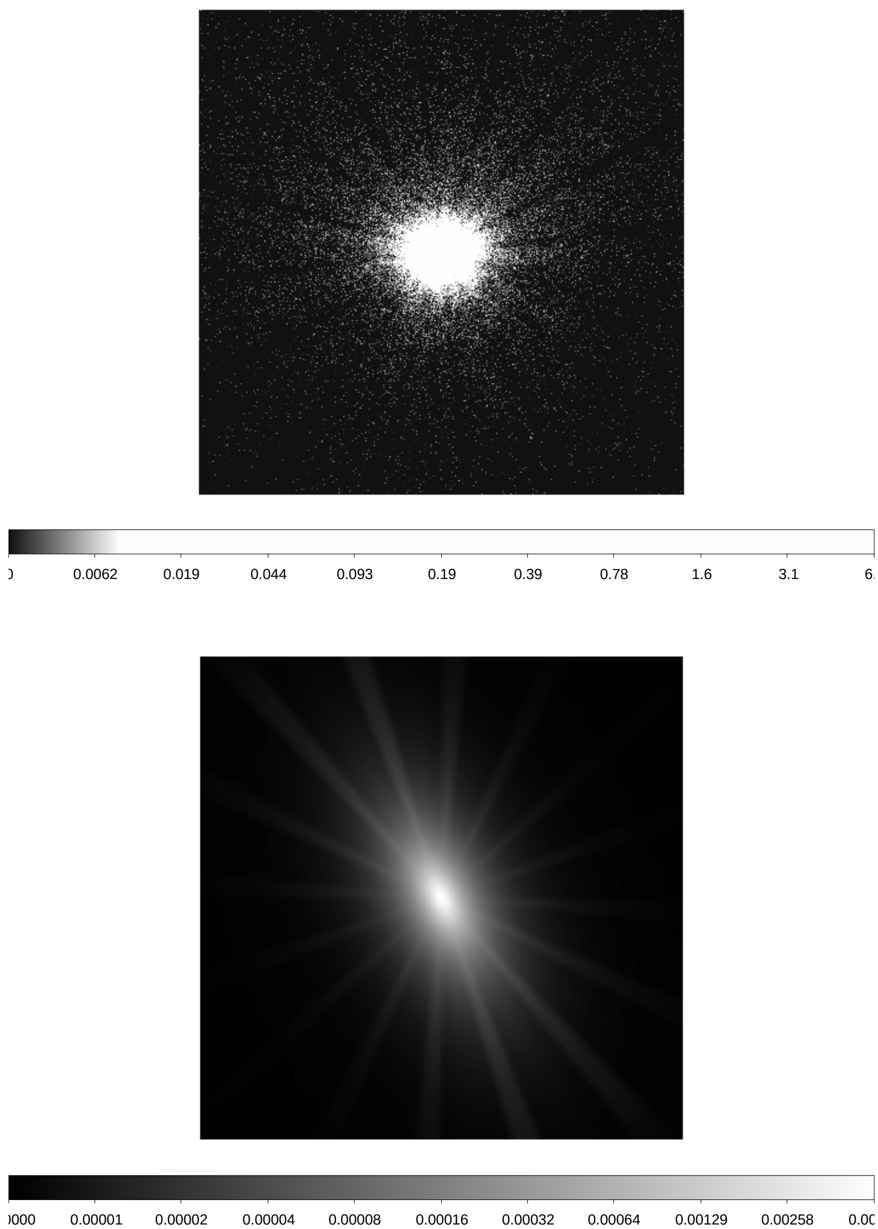

Figure 6: Upper: example 3 of psfgen user guide - MEDIUM mode MOS1 PSF at 3 arcminutes off-axis and energy of 3keV. Lower: example 5-1 from the psfgen user guide - ELLBETA mode PSF of energy 3 keV at ~ 9 arcminutes off axis.

4.8 Updated in SAS 17.0: multi-pointing mode

Changes performed to the task arfgen to cope with EPIC data taken in RGS multi-pointing mode have been tested. The ODF 0412601501, corresponding to an observation of the isolated neutron star RXJ J1856-.5-3754, has been reduced through standard processing. Spectra and response matrices of the four PN exposures corresponding to different pointings have been extracted through successive calls to especget, with the following source and background regions:

```
PN 1: srcexp='(X,Y) IN circle (26535.5,27449,1550.0)'
backexp='(X,Y) IN circle (23055.24404,870.0)'
PN 2: srcexp='(X,Y) IN circle (26535.5,27318.5,1550.0)'
backexp='(X,Y) IN circle (2383.5,24273.5,870.0)'
PN 3: srcexp='(X,Y) IN circle (26535.5,27231.5,1550.0)'
backexp='(X,Y) IN circle (28843.5,23708,870.0)'
PN 4: srcexp='(X,Y) IN circle (26535.5,27362,1550.0)'
backexp='(X,Y) IN circle (29667.23490.5,870.0)'
```

as derived graphically from the data, and with the non-standard option `useodfatt=yes` to correct for the actual attitude reference, ie.:

```
especget filestem=PN_1 withfilestem=yes srcexp='(X,Y) IN
circle(26535.5,27449,1550.0)' backexp='(X,Y) IN circle(23055.5,24404,770)'
useodfatt=yes table=data/test/multipointing/PN_1_filtered.ds.
```

Tests of the amount of pile-up using the task epatplot have taken place, by which it was found out that no significant pile-up was present for energies over 300 eV. At the same time, two different procedures have been followed with MOS data: a) the single MOS1 and MOS2 single exposures (containing all four successive sub-pointings) have been processed in the standard form. Since the background in this case can be extracted from an annulus over the peripheral CCDs, it could be not strictly necessary to follow the same procedure as for PN. Instead a simple procedure of spectral extraction with especget was followed, this time using annulii for excising the cores of the signals, due to the confirmed presence of some level of pile up. b) alternatively, we have separated the MOS1 and MOS2 event files according to the different sub-pointings. Since by this procedure, neither the DATE-OBS and DATE-END keywords indicating start and stop of the sub-pointing nor the RA_PNT and DEC_PNT keywords for the correct sub-pointing position of the optical axis in the header are modified, this has to be done through a special call to attcalc:

```
attcalc eventset=<subpoint-evtfile> setpnttouser=yes nominalra=<subp_ra>
nominaldec=<subp_dec> refpointlabel=user
```

and so the subpointing event files get the correct optical axis positions. From these event files then we have to determine source and background positions for deriving spectra and response matrices. In this case the calls to especget have to be done with `useodfatt=no`, since the coordinates are correct in each of the sub-pointing files.
Finally, the four PN and the single MOS1 and MOS2 spectra have been fitted simultaneously using a simple black body model, yielding very acceptable results for the PN data, with a BB temperature of 63.7 eV (see Fig. 7). The MOS data processed with the first alternative (a) can be hardly satisfactorily fitted even alone with a simple black body model. On the contrary, if we fit the PN and the MOS sub-pointing spectra we obtain very good results, showing the validity

of the procedure discussed as (b) alternative. Fig. 7 shows simultaneous fitting of all the 4 PN pointings and the 4 MOS1 sub-pointings. The BB temperature obtained is 63.4 eV and the normalisation factor between PN and MOS is less than 1%.

4.9 Updated in SAS 17.0: source searching

The dataset 544_0147511601 was processed with both SAS16 and SAS17; in both cases, the source detection has been performed following the corresponding thread:
https://www.cosmos.esa.int/web/xmm-newton/sas-thread-src-find
In the following, we consider as detected only sources with likelihood of detection DET_ML not lower than 25.
We found the same number of sources with SAS16 and SAS17 (144) and with consistent positions (Fig. 8).
Only one source is found in SAS16 and not in SAS17, and vice-versa; in both cases, the likelihood of detection is near the threshold (Fig. 9):
detected in sas17 not in sas16: DET_ML_17 = 27.593061, DET_ML_16 = 22.805868 detected in sas16 not in sas17: DET_ML_16 = 26.823032, DET_ML_17 = 24.971415
The distribution in counts are broadly consistent (Fig. 10).
Finally, one low-flux source (src 144; F$\sim 5 - 8 \times 10^{-15}$ ergs $s^{-1}cm^{-2}$) is considered as extended in SAS16 (EXT_16 = 2.7351813) and not in SAS17 (EXT_17 = 0.) (Fig. 11).

5 Conclusion

The SAS scientific validation process concluded that SAS 17 was validated and should be released. This occurred on June 22 2018.

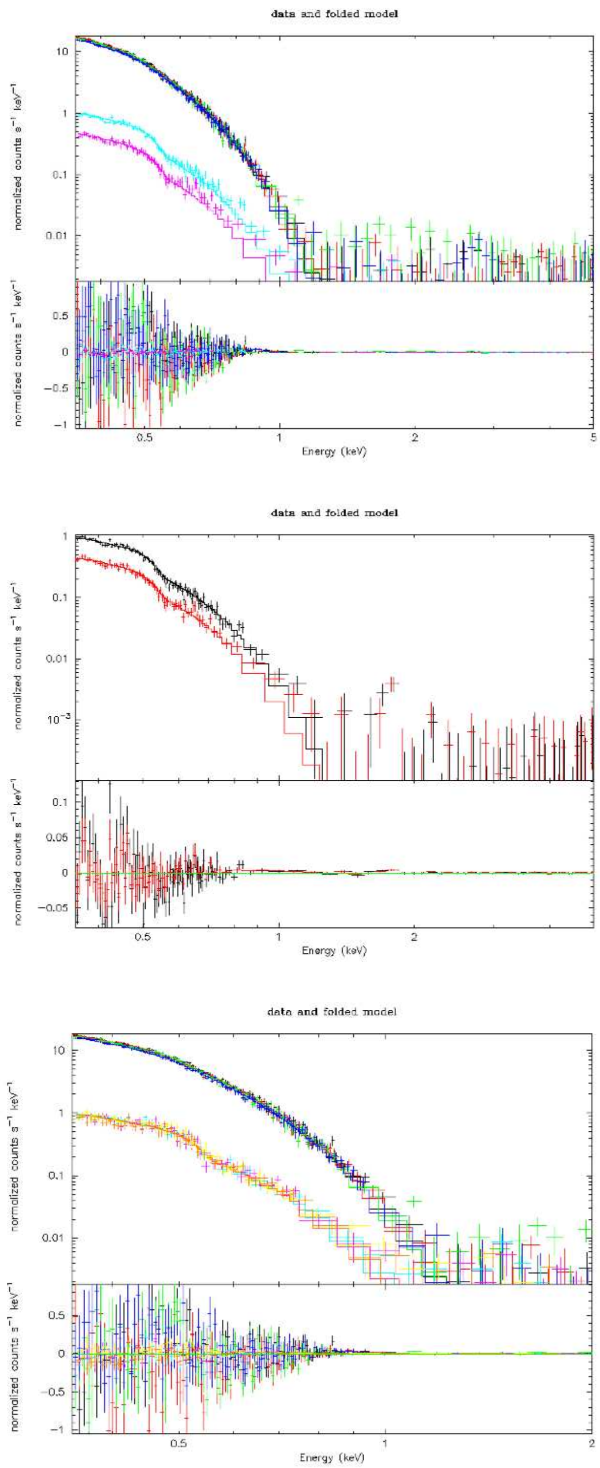

Figure 7: Upper: simultaneous fits to a multi-pointing mode observation of RXJ J1856-.5-3754 consisting of four EPIC-pn, one MOS1 and one MOS2 spectra all processed with standard processing. Middle: simultaneous fit of the MOS1 and MOS2 spectra processed with alternative (a), see text, Lower: all spectra processed with alternative (b).

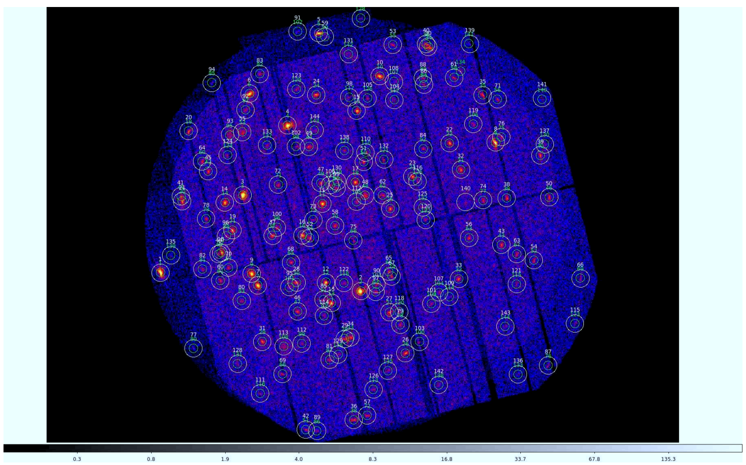

Figure 8: image from SAS16 with superimposed the sources detected in SASv16 (white bigger circles) and SASv17 (green smaller circles).

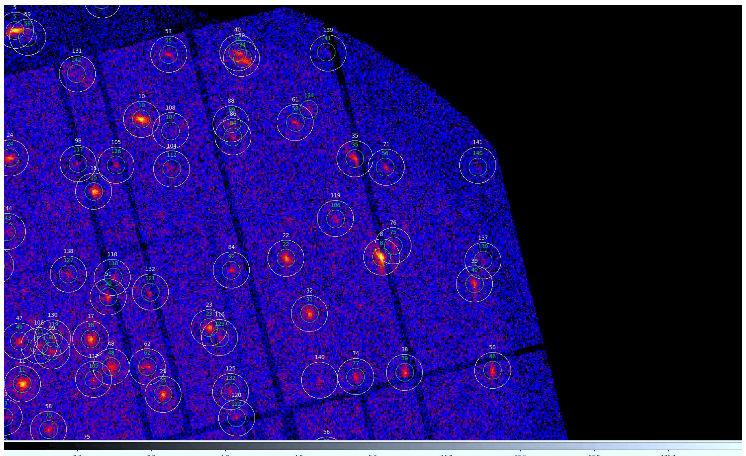

Figure 9: zoom showing the only two differences in detection (src140 from SAS16, white bigger circle; src134 from SAS17, green smaller circle).

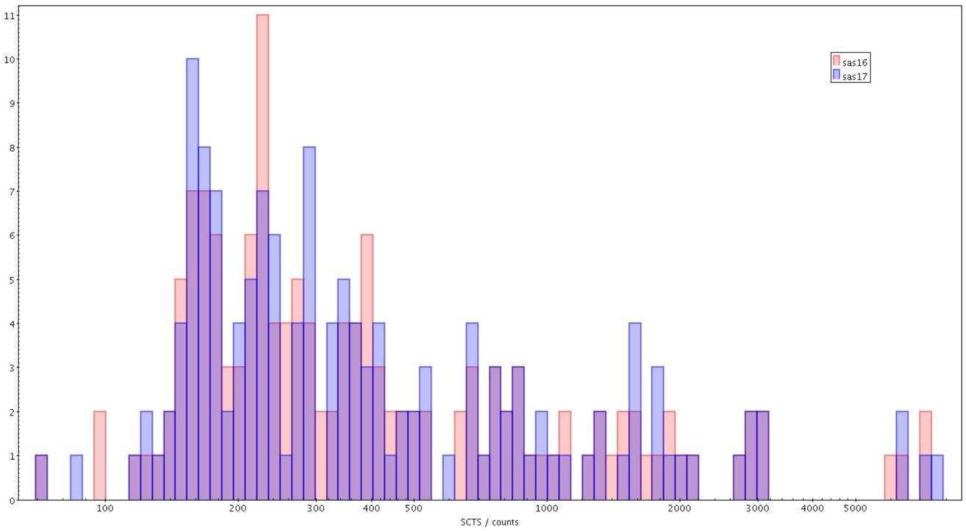

Figure 10: Histogram of counts detected in each source in SAS16 and SAS17.

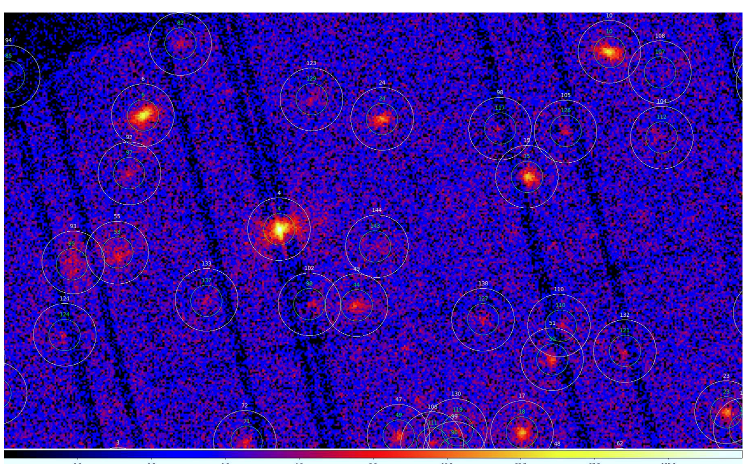

Figure 11: Zoom of source 144, which was seen as extended in SAS 16 but not in SAS 17.

References

Papadakis, I.E. et al. 2010, A&A 510, A65
Siebert, J. et al. 1999, A&A 348, 678
Tsujimoto, M. et al. 2011, A&A 525, A25