XMM-Newton

XMM-Newton Science Analysis System 18.0 scientific validation

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Revision history

Revision number	Date	Revision author	Comments
0.1	May 29, 2019	R. Saxton	first issue
1.0	June 6, 2019	R. Saxton	After comments

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 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 18.0. 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 v18.0 consisted of the following steps:

1. all the datasets listed in Tab. 1 were processed through the SAS 18 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 v18.0, 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
	UV Grism	HD13499 (offset)	657 0125911301	17	Wavelength scale

Table 1: SV datasets

Instrument	Mode	Object	Revolution Obs. ID	ID	Calibration item
					& flux calibration
	Image+Fast mode	1ES 1553+11.3	2882 0727780301	23	Jupiter patch flagging
	Image+Fast mode	1ES 1553+11.3	3242 0727780501	24	Jupiter patch flagging

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 29 March 2019, plus the following components which at this date were not yet public:

- OM_BADPIX_0007.CCF and OM_BADPIX_0008.CCF which are to be made public with the SAS 18 release, since they need to use several updated SAS packages which will be released with SAS 18.
- OM_GRISMCAL_0005.CCF also to be made public at the same time as SAS 18.

2 New and updated in SAS 18.0

Version 18.0 is a main yearly release of the SAS. The release contains the following changes which have been specifically tested.

2.1 New in SAS 18.0: production of a single time-stamped radiation monitor file

This is a convenience product, containing count rate and spectral data from the radiation monitor, which may be used by downstream SAS tasks.

2.2 New in SAS 18.0: flagging of the Jupiter Patch in OM data

An oval-shaped area of the OM detector has experienced a drop in sensitivity due to exposure to Jupiter on 2017-07-17. This area has been flagged within the OM_BADPIX CCF (see XMM-CCF-REL-368), to distinguish these pixels from bad pixels in the quality map extensions of some OM image products and downstream flag values of sources in OM source lists. These changed values apply to both previously known low-sensitivity pixels and to those in the sensitivity-degraded patch caused by the observation of Jupiter in revolution 3224. Changes to the following SAS tasks facilitate use of the new values in the CCF: **omcosflag**, **omqualitymap**, **omdetect**, **omsource**.

2.3 New in SAS 18.0: time-dependent OM grism correction

The SAS task **omgrism** has been modified to apply a time-dependent sensitivity (TDS) correction to OM grism (fluxed) spectra and insert a keyword, **TDS_CORR** into the primary header of the spectrum FITS file to convey the value. The **omgrismplot** task has also been modified to output the TDS_CORR value to the header information above the fluxed spectrum graphic. The sensitivity correction has been introduced in the calibration file OM_GRISM_0005.CCF file.

2.4 Updated in SAS 18.0: treatment of very large OM mosaics

An artifical restriction of OM image size to 3000x3000 pixels has been removed in the omdetect task.

2.5 Updated in SAS 18.0: treatment of non-standard EPIC spectra

To help normal users avoid producing spectra which can not be processed by later software, a number of warning and error messages have been added to the SAS. These cope with the cases where a spectrum has been created with a non-standard pattern selection or a non-standard PI range and binning.

2.6 Updated in SAS 18.0: emldetect

The EXT_ML value is now set for *all* sources and not just for the extended ones. A PILE_UP value has been introduced for each source, and each instrument, in the output source list.

2.7 Updated in SAS 18.0: catcorr

The sys_error has been set to 1.29 for sources in observations which have not been corrected by positional correction against astrometric reference catalogues.

2.8 Updated in SAS 18.0: handling of EPIC-pn offset maps

The correct offset map should now be used when processing datasets containing multiple offset maps and/or having multiple exposures.

2.9 Updated in SASv18.0: RGS extraction Regions in beta space

An error causing extraction regions to be incorrectly placed when using the Beta processing has been fixed.

2.10 Updated in SAS 18.0: xmmextractor

Some updates have been made to the xmmextractor task, particularly with regard to the handling of RGS data in Beta and Lambda mode.

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 32 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). This is the projected schedule:

- SAS into release track mode
- SAS builds on different platforms
- SAS 18 binaries (Linux & MacOs)
- Processing of all the standard datasets, on Linux
- Installation of SAS 18 binary in XCal grid
- Communication to validators about success and data location
- Preparation of a SAS 18 based PPS test version
- Processing of standard datasets by testing pipeline
- Processing of standard datasets also on MacOs + 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. `Radiation monitor` evaluation
  2. Flagging of the Jupiter Patch
  3. Time-dependent OM grism correction
  4. Treatment of large OM mosaics
  5. Treatment of non-standard EPIC spectra
  6. Source-searching - emldetect,catcorr
  7. Handling of EPIC-pn offset maps
  8. `xmmextractor` RGS handling

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

- Summary reports
- SAS VM produced
- Processing of all standard sets with VM
- Final SV individual reports
- Release notes + SAS 18 web pages contents ready + XMM Newsletter text
- SAS 18 distribution tar files ready
- SAS 18 release
- Final SV Report compilation

3.2 Processing of standard datasets

All the datasets listed in Tab. 1 have been processed without errors in the SciGrid (CentOS 7.5) with the RHEL6.8 build of SAS 18 release candidate. Processing times were or the order of 1 hr 20 min. Additionally, the same data sets have processed without failure on the individual building platforms, RHEL 6.8, Ubuntu 16.04LTS and macOS Sierra. Processing times were of the order of 10-11 hrs on Linux (RHEL and Ubuntu) and 8-9 hrs on MacOS.

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 17 and were found to be consistent.

3.2.2 RGS data - standard dataset

The standard set of validation data processed with the SASv18.0 build of March 29 2019 (`xmmsas_20190329_1832`) have been examined. Output products of `rgsproc` have been compared with the result of processing with previous versions of SAS. There are no significative differences.

3.2.3 SAS OM data processing

The result of using SAS 18 to process the standard validation datasets has been verified.
Analysis of the photometric information confirms that photometry obtained with SAS 18 is generally consistent with that obtained with SAS 17, within 2% for good-quality detections. Comparison of TDS-corrected count rates for the standard star, BPM16274, between SAS 18 and SAS 17 are within 1% both for the specific validation observation and for the average of all observations (all reprocessed with SAS 18) for the star.
For fast-mode time-series obtained using **omfchain** in SAS 18.0, mean count rates are consistent with those from SAS 17 to 1% or better. Individual points in timeseries are generally recovered consistently between the two SAS versions.
Analysis of astrometry in the validation set shows good consistency with the SAS 17 results. A comparison with GAIA DR2 shows 91% of spatial offsets are within 1 arcsec, with a median offset of 0.6 arcsecs

3.2.4 Test pipeline checks

The bulk re-processing of all the mission by the Pipeline was performed with the SAS 18 software (full version except for two patched tasks, rgslccorr-0.57.1 and rmfgen-2.8.1, which should not affect the pipeline runs). The processing executed correctly.

3.2.5 XCal data

The new SAS version SASv18.0 was compared with its previous version SASv17.0 by performing spectral extractions of 341 individual exposures of 52 targets of various source types throughout all the epochs of the mission that are included in the XMM-Newton SOC cross-calibration archive

- 206 exposures of on-axis point targets of various source types, mainly with continuum dominated spectra, from isolated neutron stars to AGN.
- 99 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 successfully used on a variety of different systems, including CentOs 7.3 and UBUNTU, to check for compatibility issues. SAS built on MacOs Sierra was executed on Macs running the High Sierra and Mojave operating systems without problems.

3.4 Dedicated analysis

3.4.1 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 ($\sim$ 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 SAS 18.0 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.

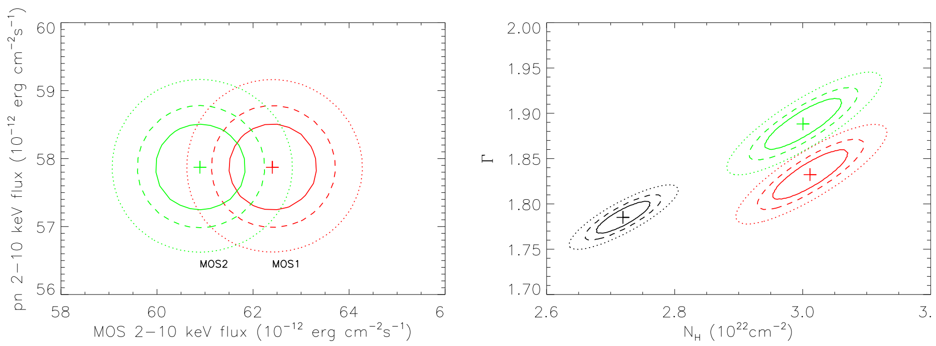

Figure 1: Comparison of PN versus MOS spectral fits of G21.5-0.9. Spectra based on data reduced with SAS 18.0, using standard pattern selection. *Left panel*: the 2-10 keV flux confidence contours for PN versus MOS1 (red) and MOS2 (green). *Right panel*: column density versus photon index confidence contours for PN (black), MOS1 (red), MOS2 (green). Levels shown are at 68%, 90% and 99% confidence.

3.4.2 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 18.0 (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 results are consistent with those obtained with the previous version of SAS.

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)	Flux 10^{-11} erg cm^{-2} s^{-1} (2.0–10.0 keV)
MOS1	$0.21^{+0.06}_{-0.04}$	$2.25^{+0.13}_{-0.14}$	$2.12^{+0.02}_{-0.02}$	$0.92^{+0.05}_{-0.06}$
MOS2	$0.32^{+0.03}_{-0.08}$	$2.09^{+0.17}_{-0.13}$	$2.30^{+0.02}_{-0.02}$	$0.94^{+0.05}_{-0.05}$
PN	$0.27^{+0.03}_{-0.03}$	$2.22^{+0.06}_{-0.06}$	$2.48^{+0.03}_{-0.03}$	$1.07^{+0.07}_{-0.06}$

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	$0.42^{+0.07}_{-0.08}$	$1.95^{+0.16}_{-0.17}$	$2.54^{+0.02}_{-0.02}$	$1.32^{+0.06}_{-0.06}$
MOS2	$0.27^{+0.06}_{-0.05}$	$2.22^{+0.11}_{-0.10}$	$2.47^{+0.02}_{-0.02}$	$1.18^{+0.05}_{-0.05}$
PN	$0.35^{+0.03}_{-0.03}$	$2.13^{+0.04}_{-0.04}$	$2.44^{+0.01}_{-0.01}$	$1.18^{+0.02}_{-0.02}$

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:

- epchain withoutoftime=true
- epchain
- emchain
- 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

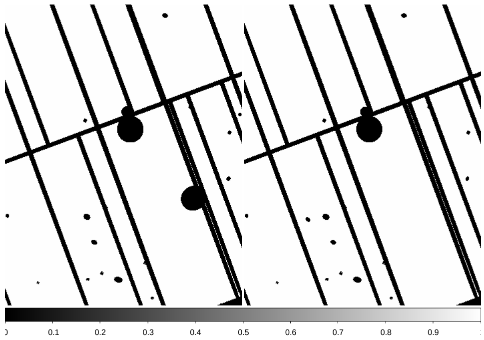

Figure 2: A mask of sources, created by the cheese task which removes regions around detected sources. Left: Mask produced by SASv17, right: mask produced using SASv18.

- rot_det_sky mode=2 prefix=S005 elow=400 ehigh=2000 detx=-1079.810798 dety=1482.314823 skyx=450.91 skyy=450.91 maskfile=1 clobber=1
- comb 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 (a smooth version of image was also produced), over the energy range elow=400 ehigh=2000. However, one bright source was not masked out by the cheese task. A run has been made with SASv17 and SASv18, and while the point source is masked out in SASv17, the same command with SASv18,
cheese prefixm='1S003 2S004' prefixp=S005 scale=0.5 rate=1 dist=40.0 clobber=0 elow=300 ehigh=10000 mlmin=15 clobber=1 verbosity=0
does not mask out the source. The problem is visible in the comparison of the two mask files (Fig. 2), where a bright source has not been removed from the right hand (SASv18) image.

3.4.4 Repeatability of OM filter photometry

As reported in section 3.2.3, the OM filter photometry is consistent with that returned by SAS 17 to within 1–2%.

4 New and updated in SAS18 - Validation

4.1 New in SAS 18.0: production of a single time-stamped radiation monitor file

The following task was run to check the production of a RADMON file.

```
epproc withradmon=yes runradmonfix=yes >& epproc.log
```

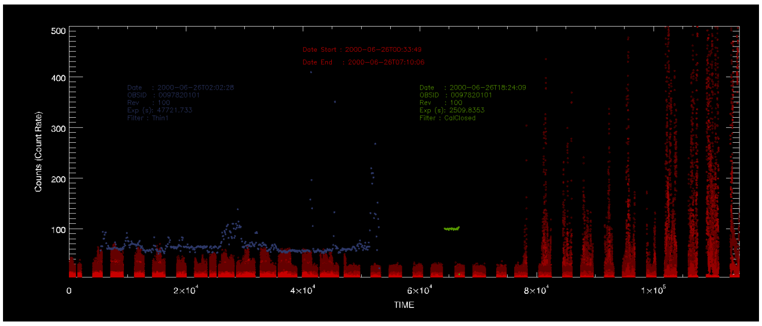

Figure 3: A combined radiation monitor file produced from observation 0097820101.

The radiation monitor file, 0100_0097820101_OBX000RADMON0000.FIT, was produced correctly using *epproc* (Fig. 3). The other tasks, emproc, epchain and emchain, currently have no option to produce this file.
In the header of the radiation monitor file, the dates for the start and end encompass the beginning and end times in the TIMECAL column as they should.
It is possible with epproc to produce radiation monitor data from the entire revolution in which the science observation was taken. The data is represented correctly, with the correct units which are clarified in the accompanying task user guide.

4.2 New in SAS 18.0: flagging of the Jupiter Patch in OM data

Both observations 2882_0727780301 (pre event) and 3242_0727780501 (post event) have been checked in SAS18-processed data.
In the pre-event case, the patch is absent from the quality images while the remaining low-sensitivity pixels are present and have values of 2048. All source flags in the source lists have values < 2048 (no sources are affected by the other low sensitivity pixels).
In the post event data, the patch appears in the quality maps with values ≥ 2048, as expected, along with the previous low sensitivity pixels. In the source list, one source is flagged with a value ≥ 2048 in the B and V filters. This looks correct as it was not detected in other filters and is the only source lying in the patch region.
The software is working correctly.

4.3 New in SAS 18.0: time-dependent OM grism correction

Spectra of Hz2 have been reduced with the SAS 18 version of **omgrism** and **omgrismplot**. The values for the TDS correction keyword (**TDS_CORR**), and the scaling of the fluxed spectra, in both the visible and UV grism cases, were verified as correct. Comparing the TDS-corrected OM visible and UV grism spectra to the Calspec spectrum of the source shows good overall agreement with it once the correction is applied. The fluxed spectrum plot displays the applied correction value in the text information above the graphic.

4.4 Updated in SAS 18.0: treatment of very large OM mosaics

Observation 0655340101 was processed manually with SAS18. It successfully ran to completion. The data comprise some 30 distinct pointings, however, the mosaic image appears to contain only two OM windows. As this case failed in the pipeline, there is no reference mosaic image to compare it to. Looking at other mosaics, in general, very large mosaics seem to be truncated at the edges, in SAS 17 and in SAS 18, somthing which will need to be addressed in a future version.

4.5 Updated in SAS 18.0: treatment of non-standard spectra

The following scenarios were run:
1. Standard spectra (standard PATTERN selection and PI channels and range)

```
evselect table=../2368_0693851801_EPN_S003_ImagingEvts.ds withspectrumset=yes
    spectrumset=PNsource_spectrum.fits energycolumn=PI spectralbinsize=5
    withspecranges=yes specchannelmin=0 specchannelmax=20479 expression='(FLAG==0)
    && (PATTERN<=4) && ((X,Y) IN circle(25299.242,23948.185,830))'
    nonStandardSpec=no >& spectrum_src.log
evselect table=../2368_0693851801_EPN_S003_ImagingEvts.ds withspectrumset=yes
    spectrumset=PNbkg_spectrum.fits  energycolumn=PI spectralbinsize=5
    withspecranges=yes specchannelmin=0 specchannelmax=20479 expression='(FLAG==0)
    && (PATTERN<=4) && ((X,Y) IN circle(22694.479,25645.001,830))'
    nonStandardSpec=no >& spectrum_bkg.log

backscale spectrumset=PNsource_spectrum.fits
    badpixlocation=../2368_0693851801_EPN_S003_ImagingEvts.ds >& backscale_src.log
backscale spectrumset=PNbkg_spectrum.fits
    badpixlocation=../2368_0693851801_EPN_S003_ImagingEvts.ds >& backscale_bkg.log

rmfgen spectrumset=PNsource_spectrum.fits rmfset=PN.rmf >& rmfgen.log

arfgen spectrumset=PNsource_spectrum.fits arfset=PN.arf withrmfset=yes rmfset=PN.rmf
    badpixlocation=../2368_0693851801_EPN_S003_ImagingEvts.ds detmaptype=psf
    >& arfgen.log

specgroup spectrumset=PNsource_spectrum.fits mincounts=25 oversample=3
    rmfset=PN.rmf arfset=PN.arf backgndset=PNbkg_spectrum.fits
    groupedset=PN_spectrum_grp.fits >& specgrp.log
```

2a. Non standard spectra, changing PATTERN and specchannel

```
evselect table=../2368_0693851801_EPN_S003_ImagingEvts.ds withspectrumset=yes
    spectrumset=PNsource_spectrum_PT6.fits energycolumn=PI spectralbinsize=5
    withspecranges=yes specchannelmin=300 specchannelmax=8000 expression='(FLAG==0)
    && (PATTERN<=6) && ((X,Y) IN circle(25299.242,23948.185,830))'
    nonStandardSpec=yes >& spectrum_src_PT6.log
evselect table=../2368_0693851801_EPN_S003_ImagingEvts.ds withspectrumset=yes
    spectrumset=PNbkg_spectrum_PT6.fits  energycolumn=PI spectralbinsize=5
    withspecranges=yes specchannelmin=300 specchannelmax=8000 expression='(FLAG==0)
    && (PATTERN<=6) && ((X,Y) IN circle(22694.479,25645.001,830))'
    nonStandardSpec=yes >& spectrum_bkg_PT6.log
```

```
backscale spectrumset=PNsource_spectrum_PT6.fits
    badpixlocation=../2368_0693851801_EPN_S003_ImagingEvts.ds >&
    backscale_src_PT6.log
backscale spectrumset=PNbkg_spectrum_PT6.fits
    badpixlocation=../2368_0693851801_EPN_S003_ImagingEvts.ds >&
    backscale_bkg_PT6.log

rmfgen spectrumset=PNsource_spectrum_PT6.fits rmfset=PN_PT6.rmf >& rmfgen_PT6.log
```

2b. Non standard spectra, changing only specchannel

```
evselect table=../2368_0693851801_EPN_S003_ImagingEvts.ds withspectrumset=yes
    spectrumset=PNsource_spectrum_PT4.fits energycolumn=PI spectralbinsize=5
    withspecranges=yes specchannelmin=300 specchannelmax=8000 expression='(FLAG==0)
    && (PATTERN<=4) && ((X,Y) IN circle(25299.242,23948.185,830))'
    nonStandardSpec=yes >& spectrum_src_PT4.log
evselect table=../2368_0693851801_EPN_S003_ImagingEvts.ds withspectrumset=yes
    spectrumset=PNbkg_spectrum_PT4.fits  energycolumn=PI spectralbinsize=5
    withspecranges=yes specchannelmin=300 specchannelmax=8000 expression='(FLAG==0)
    && (PATTERN<=4) && ((X,Y) IN circle(22694.479,25645.001,830))'
    nonStandardSpec=yes >& spectrum_bkg_PT4.log

backscale spectrumset=PNsource_spectrum_PT4.fits
    badpixlocation=../2368_0693851801_EPN_S003_ImagingEvts.ds >&
    backscale_src_PT4.log
backscale spectrumset=PNbkg_spectrum_PT4.fits
    badpixlocation=../2368_0693851801_EPN_S003_ImagingEvts.ds >&
    backscale_bkg_PT4.log

rmfgen spectrumset=PNsource_spectrum_PT4.fits rmfset=PN_PT4.rmf acceptchanrange=yes
    >& rmfgen_accept_PT4.log

arfgen spectrumset=PNsource_spectrum_PT4.fits arfset=PN_PT4.arf withrmfset=yes
    rmfset=PN_PT4.rmf badpixlocation=../2368_0693851801_EPN_S003_ImagingEvts.ds
    detmaptype=psf >& arfgen_PT4.log

specgroup spectrumset=PNsource_spectrum_PT4.fits mincounts=25 oversample=3
    rmfset=PN_PT4.rmf arfset=PN_PT4.arf backgndset=PNbkg_spectrum_PT4.fits
    groupedset=PN_spectrum_grp_PT4.fits >& specgrp_PT4.log
```

The results were:
1. Standard spectra (standard PATTERN selection and PI channels and range). All steps ok. The spectra can be viewed with XSPEC.
2a. Non standard spectra, changing PATTERN and specchannel

- eveselect issues a warnings when PATTERN≤ 6 and specchannelmin=300 specchannelmax=8000 and nonStandardSpec=no

```
** evselect: warning (NonStandardSpectrum), The standard event PATTERN
   range for a PN spectrum is 0-0, 0-1, 0-4 or 1-4. Detector matrices
   can not be created for this spectrum and spectral fitting will not
   be possible.
```

- eveselect does not issue any warnings when PATTERN≤ 6 and specchannelmin=300 specchannelmax=8000 and nonStandardSpec=yes - backscale issues for PATTERN≤ 6 and specchannelmin=300 specchannelmax=8000 the following warning:

```
** backscale::arfgen: warning (NonStandardPatterns), Non-standard
   pattern range - assuming energy pattern fraction = 1.0
```

- rmfgen issues for PATTERN≤ 6 and specchannelmin=300 specchannelmax=8000 the following error:

```
** rmfgen: error (NonStandardChanRange), the input spectrum uses the
   channel range PI = 300 - 8004 but it should contain the standard
   range of PI = 0 - 20479. You may force rmfgen to run anyway using the
   parameter acceptchanrange=yes but the RMF produced will not be correctly
   normalised
```

- rmfgen issues for PATTERN≤ 6 and specchannelmin=300 specchannelmax=8000 and acceptchanrange=yes the following error:

```
** rmfgen: error (InvalidPatterns), An RMF cannot be produced for the
           pattern range in the DSS no rmf can be generated.
```

2b. Non standard spectra, changing only specchannel
- no warning from backscale if PATTERN≤ 4 and only specchannelmin=300 specchannelmax=8000 are changed. Only if a non-standard PATTERN value is introduced does backscale complain.
- rmfgen issues the following warning. The file PN_PT4.rmf is produced.

```
* rmfgen: warning (invalidCCFChannels), Can't rebin channel boundaries
  from the CCF - using regular bins
```

- arfgen does not issue any warnings
- specgroup does not issue any warnings
The spectra can be viewed with XSPEC and the cut 0.3 eV to 8 keV is clear.

4.6 Updated in SAS 18.0: emldetect

The dataset 0544_0147511601 was used to check the changes in emldetect. The observation was processed with SAS 17 and SAS 18. In the comparison only sources with likelihood of detection $DET\_ML > 25$ were considered. We found 145 sources with SAS17 and 148 sources with SAS18. Source detections are shown in Fig. 4. Positions are consistent to within 1–5 arcsecs, with a maximum of 7 arcsec for one source.
All sources found in SAS17 are also found in SAS18; three sources are found in SAS18 and not in SAS17: in the three cases, the likelihood of detection is near the threshold, although for one source the difference in likelihood between SAS17 and SAS18 is not negligible.

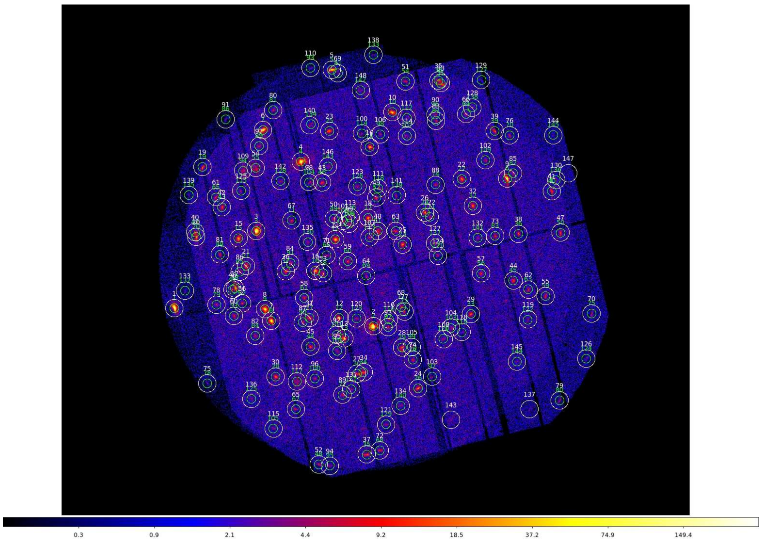

Figure 4: Detections of sources in observation 0147511601 by SAS 17 (green smaller circles) and SAS 18 (white bigger circles).

```
DET_ML_18 = 29.564919, DET_ML_17 = 22.76164, threshold 25
DET_ML_18 = 25.479382, DET_ML_17 = 22.144823, threshold 25
DET_ML_18 = 26.197844, DET_ML_17 = 10.704969, threshold 25
```

The distribution of counts is consistent between the two SAS versions (Fig. 5).
One source (source 134 from SAS17) is considered as extended in SAS17 (EXT=1.616) and not in SAS18 (EXT=0). This source is relatively faint ($F \sim 1.3 \times 10^{-14}$ ergs $s^{-1}cm^{-2}$).
As expected, in SAS18 the EXT_ML value is set for all sources; for each source, the same value is set for each band and for each instrument (irrespective of the detection in a specific camera - SCTS not set).
The PILE_UP value is set for band 0 for each instrument individually where the source was detected and where the ONTIME value is non-zero. The values appear to be commensurate with the source count rate and observing mode. Detections which are affected by chip gaps etc. do not get a PILE_UP value assigned, which is as expected.

4.7 Updated in SAS 18.0: catcorr

The dataset 1696_0555690601 (chosen for the relatively short exposure time, 4470ks, and the low number of EPIC sources detected) was processed with both SAS17 and SAS18; in both cases, the source detection was performed following the thread:
https://www.cosmos.esa.int/web/xmm-newton/sas-thread-src-find
The final EPIC summary source list was produced by running the srcmatch SAS task with the EPIC emldetect source list as input; finally, the catcorr SAS task has been used, assuming as reference catalogue the file produced by the pipeline (P0147511601OBX000REFCAT0000.FIT).
In the resulting file, for all the 5 detected sources the SYSERRCC value is set to 1.29 in SAS18 and to 1.5 in SAS17.
While catprep and catcorr can be used as advertised in the pipeline at the SOC, they can not be used easily by an external user. The documentation has been updated to reflect this in new minor versions of each task.

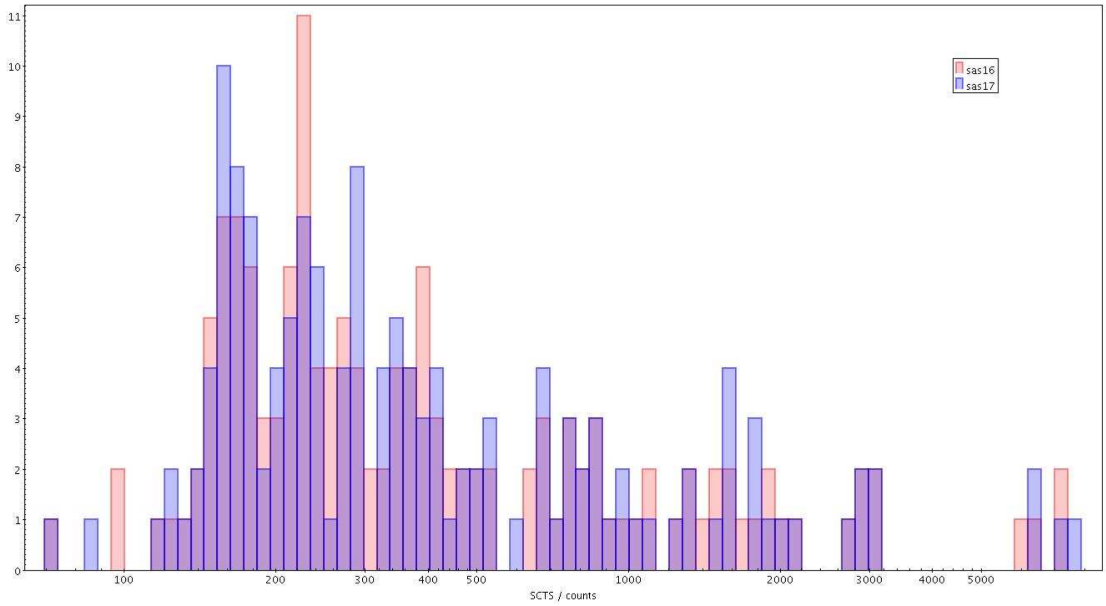

Figure 5: Histogram of the counts in each source from observation 0147511601.

4.8 Updated in SAS 18.0: handling of EPIC-pn offset maps

The observation 0510390901, containing 3 offset maps and three exposures. It was checked that the software, `epproc`, accessed the correct offset map for each exposure. Exposure 1 (PNS016), with start time 2015-05-23T06:00:35, accessed offset map 2830_0510390901_PNU70001ODI.FIT, made at time, 2015-05-23T05:51:58; exposure 2 (PNS017), with start time, 2015-05-23T18:31:45, accessed offset map 2830_0510390901_PNU70101ODI.FIT, made at time, 2015-05-23T18:23:07 and exposure 3 (PNS005), start time = 2015-05-24T06:00:37, used the offset map 2830_0510390901_PNU70201ODI.FIT, made at time 2015-05-24T05:52:00. Hence it is confirmed that the software is working correctly.

4.9 Updated in SAS 18.0: RGS extraction regions in beta space

It has been found that the RGS extraction masks defined in the source list generated in SASv17 with the (non-default) option `spectrumbinning=beta` were misplaced (see Fig.6). The use of these regions was then leading to wrong extracted spectra, as shown in the top panels of Fig. 7. The impact of this error is minor as the default processing option is `spectrumbinning=lambda` since SASv10.
The reason for the displacement was the application of the 'Sun Angle' and 'Heliocentric' corrections to the position of the regions even in the case they were computed in Beta space. This bug has been corrected in SASv18.

4.10 Updated in SAS 18.0: xmmextractor RGS handling

`xmmextractor` was run on observation 0134522201. The first run used the default option of processing the RGS data using the *lambda* option. Then the xmmextractorParam.xml control file was changed so that the task ran in *beta* mode. The output RGS files from both runs were compared and found to give consistent answers.

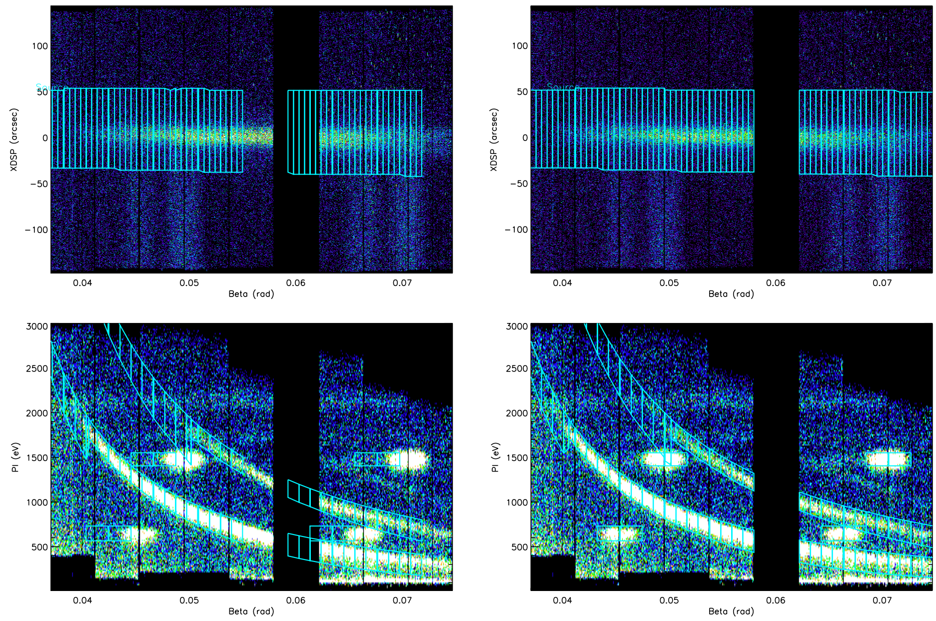

Figure 6: Example of the extraction regions for an RGS2 exposure. Left panel shows the regions derived with SASv17 using the option 'spectrumbinning=beta'. Right panel is similar, but for SASv18, showing that the extraction masks are now properly placed.

5 Conclusion

The validation excercise resulted in updated versions of the following tasks:

- catprep (v0.5.4), catcorr (v0.11.1) - documentation
- xmmextractor (v1.11.14) - bug fix
- radmonfix (v0.5.2) - documentation clarifications

The SAS scientific validation process concluded that SAS 18 was validated and should be released.

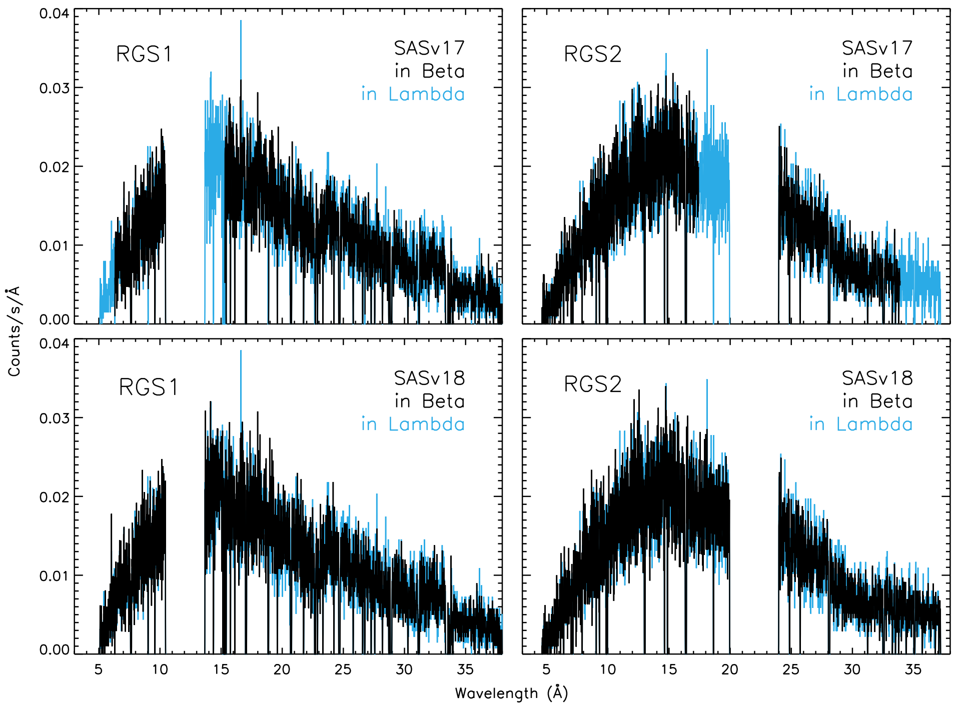

Figure 7: Effect of the use of an incorrect extraction region in the final spectrum. Shown are examples for SASv17 (top) and SASv18 (bottom). Plotted in blue are spectra extracted with `spectrumbinning=lambda`, that are correct in both SAS versions. Spectra plotted in black are those obtained with `spectrumbinning=beta`, wrong in SASv17, correct in SASv18.

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