XMM-Newton

XMM-Newton Science Analysis System 20.0 scientific validation

XMM-SOC-USR-TN-0036 Issue 1.0

R. Saxton, E. Ojero, I. de la Calle, A.Ibarra,
J.V.Perea, P.Rodríguez, M. Smith, M.Stuhlinger,
J. Ebrero, L Ballo, S. Rosen, S. Migliari, I. Valtchanov, C. Sanchez
XMM-Newton Science Operations Centre

March 27, 2022

Revision history

Revision number	Date	Revision author	Comments
1.0	Mar 27, 2022	R. Saxton	Version for public release
0.2	Mar 4, 2022	R. Saxton	after internal revision
0.1	Feb 22, 2022	R. Saxton	first issue

Contents

1 Introduction **1**
1.1 Methodology . . . 1
1.2 Validation schedule . . . 3
1.3 Calibration data used . . . 4

2 New and updated in SAS 20.0 **4**
2.1 Updated in SAS 20.0: Specific OM updates . . . 5
2.2 Updated in SAS 20.0: combine spectra from different cameras . . . 5
2.3 Updated in SAS 20.0: produce QPB products . . . 5
2.4 New in SAS 20.0: Sensitivity maps in units of flux . . . 5
2.5 Fixed in SAS 20.0: EPIC-pn Filter problem . . . 5
2.6 New in SAS 20.0: Absolute Effective Area correction . . . 5
2.7 Updated in SAS 20.0: Barycen solar system ephemeris . . . 5
2.8 Updated in SAS 20: `esas` . . . 5
2.9 Python support within SAS . . . 5
2.9.1 pysas . . . 5
2.9.2 Packages migrated to python . . . 6

3 Validation results: standard tests **6**
3.1 Processing of standard datasets . . . 6
3.1.1 EPIC data - standard set . . . 6
3.1.2 RGS data - standard dataset . . . 6
3.1.3 OM data processing . . . 7
3.1.4 Repeatability of OM filter photometry . . . 7
3.1.5 Test pipeline checks . . . 8
3.1.6 XCal data . . . 8
3.2 Processing with SAS built on different operating systems . . . 10
3.3 Dedicated analysis . . . 10
3.3.1 G21.5-0.9 . . . 10
3.3.2 PKS 0558-504 . . . 10
3.3.3 Standard tests of `esas` . . . 11
3.4 Source searching . . . 13

4 Validation results: New and updated features in SAS 20 **13**
4.1 Test of RGS and EPIC observations with repeated frames problem . . . 13
4.2 Specific OM updates . . . 13
4.3 Combine spectra from different cameras over different energy ranges . . . 15
4.4 Produce QPB products . . . 15
4.5 RGS background smooth technique . . . 15
4.6 Sensitivity maps in units of flux . . . 16
4.7 Fix EPIC-pn Filter problem . . . 16
4.8 Test Absolute Effective Area correction . . . 16
4.9 Barycen solar system ephemeris . . . 16

5 Validation results: Python support **16**

5.1 pysas: testing SAS python threads from notebooks and CLI 17

5.1.1 sas-startup from a python script 17

5.1.2 sas-startup thread 17

5.1.3 epic-reprocessing 17

5.2 Packages migrated to Python 17

6 Conclusion **18**

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 20.0. 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.
The validation reported here follows the SAS 20 Validation Plan, XMM-SOC-USR-TN-0035, please refer to that document for more details.

1.1 Methodology

The SV for SAS v20.0 consisted of the following steps:

1. all the datasets listed in Tab. 1 were processed through the SAS 20 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` or `eslewchain` for slew datasets. This took place on the SciGrid and also on each SAS builder used to produce the SAS release candidate, both Linux and macOS.

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

4. the whole cross-calibration database was processed using the same SAS release candidate, including model fitting through Xspec. This is to ensure that the cameras return fluxes consistent with the known cross–calibration errors.

5. 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 v20.0, and compare it with the expected accuracy on the basis of the calibration status at the time the SV is performed.

6. SAS v20.0 includes changes in the support for Python scripting and programming. This has been validated separately.

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 & flux calibration

Table 1: SV datasets

Instrument	Mode	Object	Revolution Obs. ID	ID	Calibration item
	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 Validation schedule

This SAS version will be released in the Linux OS 64 versions (Ubuntu 18.04LTS and 20.04LTS and CentOs 7.3) and the MacOs versions Catalina and Big Sur (see the SAS Validation Plan - XMM-SOC-USR-TN-0035 - for a fuller description). A Virtual machine and Docker versions, both based on Ubuntu 20.04 LTS were also produced.
The schedule for the validation foresees a total of around 8 weeks for performing the different tasks (for the period from going into release track mode to final release). This was the projected schedule:

- SAS into release track mode
- Produce binaries for first SAS 20 release (Linux & macOs).
- Install release candidates in all builders.
- Processing of all the standard datasets, on SciGrid (CentOS 7.3)
- Processing of all the standard datasets, on each SAS builder (Linux and macOS)
- Installation of SAS 20 binary in XCal grid
- Communication to validators about success and data location
- Preparation of a SAS 20 based PPS test version on xmmggw6
- Processing of standard datasets by testing pipeline
- Processing of XCal archive
- Testing of ESAS
- First I/A analysis of standard data
- Run X-cal datasets and evaluate results
- Python task validation
- Integrity checks running all the existing SAS threads
- Dedicated analysis (see section 2)
    1. Test of RGS and EPIC observations with repeated frames problem
    2. Specific OM updates

3. Combine spectra from different cameras over different energy ranges
4. Produce QPB products
5. RGS background smooth technique
6. Sensitivity maps in units of flux
7. EPIC-pn Filter problem
8. Test Absolute Effective Area correction
9. Barycen solar system ephemeris options

- Summary reports
- SAS VM produced
- Final SV individual reports
- Release notes + SAS 20 web pages contents ready + XMM Newsletter text
- SAS 20 distribution tar files ready
- SAS 20 release
- Final SV Report compilation

1.3 Calibration data used

SASv20 was validated using the full public calibration constituents available on 28 Sep 2021, plus some CCFs needed by a new version of ESAS which were:

- EMOS1_FWC_0004.CCF, EMOS2_FWC_0004.CCF, EPN_FWC_0004.CCF
- XMM_FLARE_0001.CCF
- XMM_SCALEFACTORS_0001.CCF
- XMM_SPDETMAP_0001.CCF
- XMM_SWCX_0001.CCF
- EMOS1_QPB_0001.CCF, EMOS2_QPB_0001.CCF, EPN_QPB_0001.CCF. Note that the QPB calibration files are not strictly speaking CCFs and are actually stored in the testprods directory of the SAS.

In addition, a CCF, XRT1_XAREAEFF_0014.CCF, was generated with dummy data to test the software providing the absolute effective area correction (Sect. 2.6).

2 New and updated in SAS 20.0

Version 20.0 is a main yearly release of the SAS. The release contains the following changes which have been specifically tested.

2.1 Updated in SAS 20.0: Specific OM updates

omichain, comments which were missing have been reinstated.

2.2 Updated in SAS 20.0: combine spectra from different cameras

epicspeccombine now allows data from the EPIC cameras to be added over different energy ranges, e.g. MOS cameras to 12 keV and EPIC-pn up to 15 keV.

2.3 Updated in SAS 20.0: produce QPB products

A task, qpbselect, which produces spectra or images from quiescent particle background (QPB) data has been modified so that it no longer needs to have the ODF specified.

2.4 New in SAS 20.0: Sensitivity maps in units of flux

A new algorithm to optionally produce the sensitivity map in units of flux rather than counts has been added to esensmap.

2.5 Fixed in SAS 20.0: EPIC-pn Filter problem

When the temperature is lower than normal (e.g. due to one of the other instruments being off), the sensor for the position of the EPIC-pn filter wheel can show the wrong position. This has been fixed. It should be tested on obsid 0820310401 to ensure that the fix works.

2.6 New in SAS 20.0: Absolute Effective Area correction

The CAL and arfgen have been updated to use an absolute effective area correction available in the XRT3_XAREAEF CCF. NB: The final numbers for the correction are not yet available and tests will use a dummy CCF.

2.7 Updated in SAS 20.0: Barycen solar system ephemeris

The task barycen has been updated to be able to use any available ephemeris file.

2.8 Updated in SAS 20: `esas`

It proved to be impossible to get a full new version of ESAS, including SAS calibration files and modular tasks, to run end to end. It was decided to roll back to a version which is principally the SAS 19.1 version plus some bug fixes. The validation of this package is described in Sect. 3.3.3.

2.9 Python support within SAS

2.9.1 pysas

The following tests should be run to validate the pysas module:

- Choose selected ODFs from the Standard Validation Set (Table 1) and execute the following sequence of Python tasks from either an ipython or a Jupyter Notebook session, using the pysas wrapper module:

  1. sasver 2. startsas 3. emproc, epproc, rgsproc, omichain and omgchain.

- Run the complete SAS Threads in Python as documented. Check in all cases that the output products (event files, light curves, spectra, plots, images) are correct.

2.9.2 Packages migrated to python

New Python versions of the PGPLOT based packages included in SAS 20 should be tested by selecting specific input products similar to those used in the specific package's test harnesses. These tests should be done on both the CLI using different sets of parameters and the pysas wrapper module, from a running Jupiter Notebook. The following packages are included: ombackground, omdrifthist, rgsimplot, rgsspecplot, eslewchain.

3 Validation results: standard tests

3.1 Processing of standard datasets

All the datasets listed in Tab. 1 have been processed without errors using the SAS 20 release candidate xmmsas_20211130_0941 using CentOS 7.3 in the SciGrid. Processing time was 1hr for the whole standard data set. Slow processing runs were done on Ubuntu18.04 and macOS Catalina machines and took 11-12 hours. No processing was done with RHEL.

3.1.1 EPIC data - standard set

The standard EPIC datasets were processed without any obvious errors being produced. Results were compared with the processing from SAS 19 and were found to be consistent.

3.1.2 RGS data - standard dataset

The standard set of validation data processed with the SASv20.0 build of October 18 2021 (xmmsas_20211018_1931) have been examined. Output products of rgsproc have been compared with the result of processing with previous versions of SAS. There are no significant differences.

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
Abs. Effective Area	Effective Area matrix (ARF)	Fluxes
Photometry	Source lists	Fluxes

3.1.3 OM data processing

As in previous SAS deliveries, this Science validation has been devoted to checking and confirming that the main functionalities already present in previous versions are maintained, in other words, we confirm the overall stability of the system. The reader is thus referred to previous Science Validation Reports for more detailed comments or descriptions.
The output products of SAS 20 have been verified on the standard OM validation data sets. Comparisons of the photometry, astrometry, grism spectroscopy and fast mode products processed with SAS 20, against those from SAS 19, all show very good consistency. Photometric tests show agreement is well within 1% of SAS 19 results while astrometry differences are within 0.03 arcsecs. Checks against reference data (e.g. GAIA DR2 for astrometry, and spectrophotometric standards for photometry and spectroscopy) confirm the validity and stability of SAS 20 for the OM - the mean astrometric offset with respect to GAIA DR2 positions is 0.62 srcsecs, consistent with the known OM residual uncertainties $\sim$0.7 arcsecs due to the OM distortion map.

3.1.4 Repeatability of OM filter photometry

Several spectrophotometric standard stars are observed regularly with OM in order to establish and monitor the photometric and flux calibrations. We have reprocessed all the data from one of them, BPM16274, using SAS 20.
The results are presented in Table 3. For comparison we give also the results obtained with SAS 19 - note the SAS 19 results are based on calibration data at the time of the SAS 19 release. The data used span the mission baseline, up to revolution 3743 (the interval of temporal overlap with SAS 19) but exclude observations beyond revolution 3224 if the source was observed within the so-called 'Jupiter' patch, where the sensitivity degradation is not corrected for.
The quoted errors are the standard deviations of the data about the mean values, given as a percentage of the mean.
We see that after all corrections are applied, the standard deviation of the count rate of the star obtained in each filter is less than 2.5%. The data also confirm that SAS 20 delivers very similar count rate results to SAS 19 ($<$ 1% differences).

Table 3: A comparison of the average count rates (per filter) of all observations of the standard star, BPM16274, up to revolution 3743 (but excluding those where the source is affected by the Jupiter patch degradation), processed with SAS 20 and SAS 19. Errors are the standard deviations of the data, as a percentage of the mean. Note that the larger errors in the V and UVW2 filters arise, mainly, from small but systematic, unexplained trends in these two bands over the mission baseline.

SAS	UVW2	UVM2	UVW1	U	B	V
20	14.67	29.93	72.42	112.08	106.74	32.93
error (%)	1.8	1.1	1.0	0.8	1.0	2.3
19	14.63	29.99	72.37	112.13	106.93	32.81
error (%)	1.6	1.0	1.0	0.8	0.9	2.2

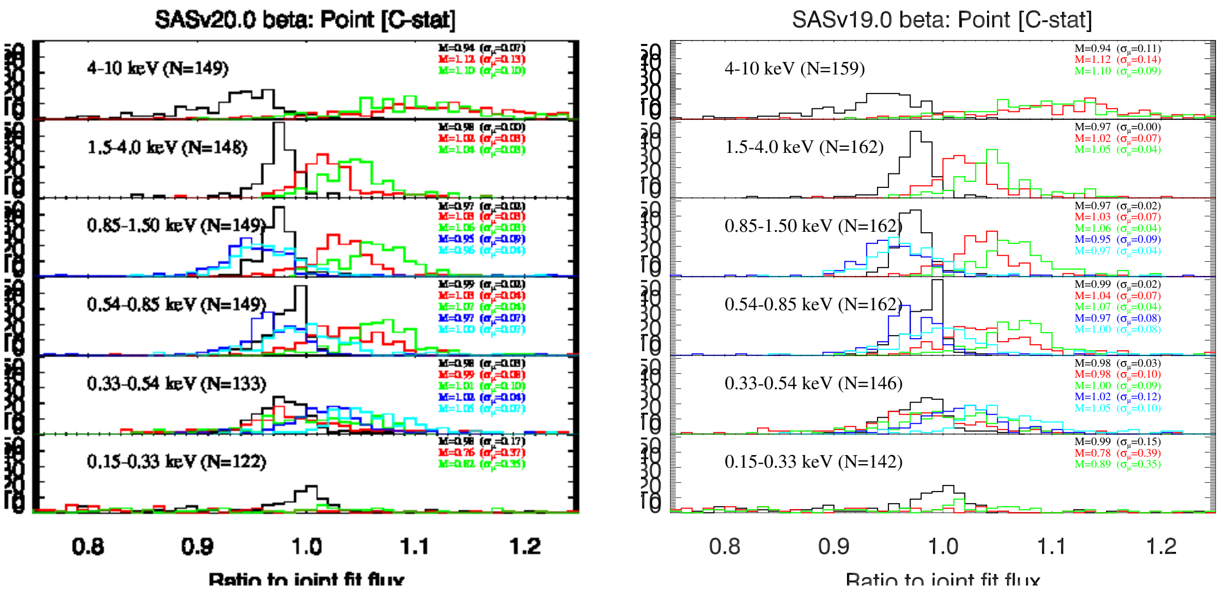

Figure 1: *Left panel*: comparison of fluxes returned on a set of point sources by the three EPIC cameras and the RGS, using SAS v20.0. *Right panel*: comparison of fluxes using SAS v19.0.

3.1.5 Test pipeline checks

All the validation dataset ODFs were successfully processed in a SASv20 based Pipeline.

3.1.6 XCal data

The new SAS version SASv20.0 was compared with its previous version SASv19.0 by performing spectral extractions of 340 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

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

All results of the spectral extractions using the two different versions of the SAS show comparable differences between the camera returned fluxes (Fig. 1).
The line strengths returned by a multi-component fit to the SNR 1E0102.2-7219 were compared between SAS 20 and SAS 19 (Fig. 2) giving consistent results.

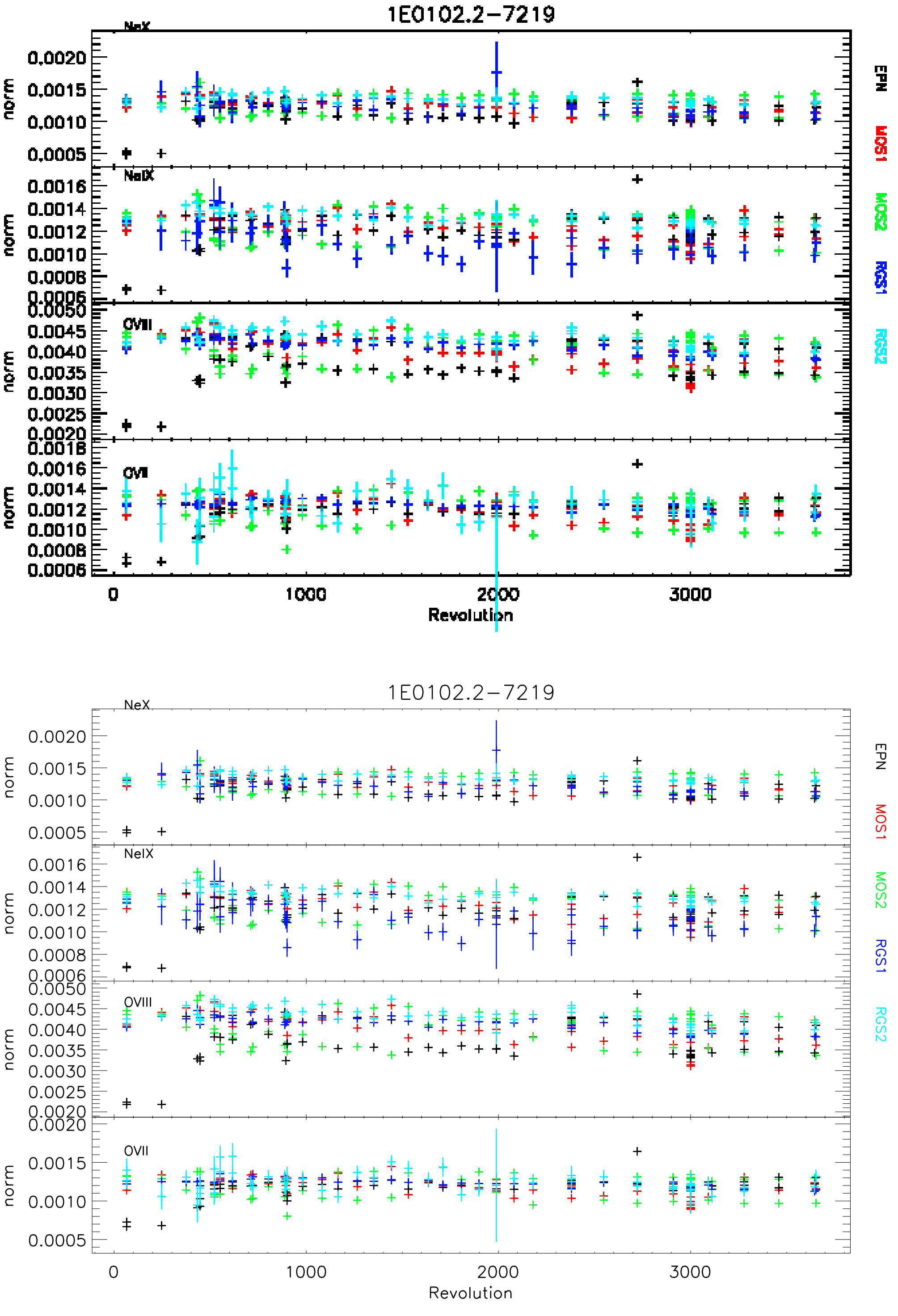

Figure 2: Measured line strengths, as a function of epoch, for spectral fits to the SNR 1E0102.2-7219 with SAS v20 (upper) and SAS v19 (lower).

3.2 Processing with SAS built on different operating systems

The Linux versions (Centos 7.3, Ubuntu 18.04LTS and Ubuntu 20.04LTS) and macOS Catalina have been successfully built and ran. Functionality has been tested successfully on macOS Big Sur on an M1 processor. The processing run of the XMM-Newton Pipeline used RHEL6 on ESAGrid.

3.3 Dedicated analysis

3.3.1 G21.5-0.9

The non-thermal SNR G21.5-0.9 is 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 SAS 20.0 and spectra were extracted with standard event pattern selection.
The results of the comparison of PN and MOS are summarised in Fig. 3, and are essentially in agreement with the previous SAS science validation study. This is as expected, as no significant changes in energy scale calibration for imaging modes have been introduced in the meantime.

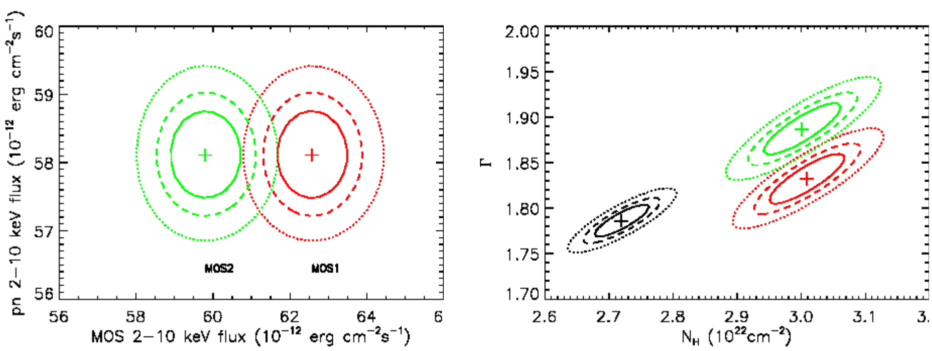

Figure 3: Comparison of PN versus MOS spectral fits of G21.5-0.9. Spectra based on data redu ced with SAS 20.0, using standard pattern selection. *Left panel*: the 2-20 keV flux confidence contours for PN versus MOS1 (red) a nd MOS2 (green). *Right panel*: column density versus photon index confidence contours for PN (black), MOS1 (red), MOS2 (green). Levels shown are at 68%, 90% and 99% confidence.

3.3.2 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 20.0 (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 absorption 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 4 and 5. 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.
The results are fully consistent with the previous SAS science validation study.

Table 4: 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)
PN	$0.28^{+0.03}_{-0.03}$	$2.22^{+0.06}_{-0.06}$	$2.48^{+0.03}_{-0.03}$	$1.07^{+0.07}_{-0.06}$
MOS1	$0.23^{+0.07}_{-0.05}$	$2.22^{+0.13}_{-0.16}$	$2.14^{+0.02}_{-0.02}$	$0.92^{+0.05}_{-0.06}$
MOS2	$0.32^{+0.05}_{-0.08}$	$2.10^{+0.17}_{-0.14}$	$2.30^{+0.02}_{-0.02}$	$0.93^{+0.06}_{-0.05}$

Table 5: 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)	Flux 10^{-11} erg cm^{-2} s^{-1} (2.0–10.0 keV)
PN	$0.35^{+0.03}_{-0.03}$	$2.13^{+0.05}_{-0.04}$	$2.44^{+0.01}_{-0.01}$	$1.18^{+0.02}_{-0.02}$
MOS1	$0.41^{+0.09}_{-0.08}$	$1.92^{+0.16}_{-0.19}$	$2.54^{+0.02}_{-0.02}$	$1.35^{+0.06}_{-0.06}$
MOS2	$0.27^{+0.06}_{-0.05}$	$2.22^{+0.10}_{-0.12}$	$2.47^{+0.02}_{-0.02}$	$1.18^{+0.05}_{-0.05}$

3.3.3 Standard tests of `esas`

The version, esas-0.11.4, was tested to ensure that it ran successfully. 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
- emanom (mos-1 and mos-2)
- espfilt
- 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
- 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.
Cheese removes a point source correctly when it did not in the previous SAS19 version. Compared with SAS 19, the new version excludes less sources. A visual inspection indicates that the new version is more accurate.

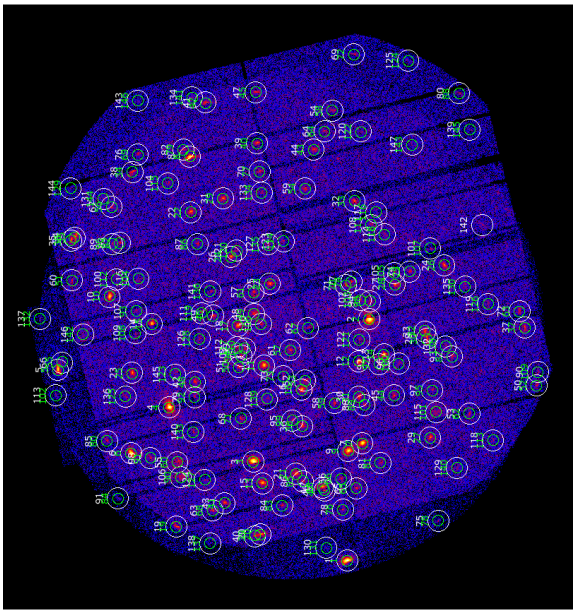

Figure 4: image from SAS20 with superimposed the sources detected in SAS20 (white bigger circles) and SAS19 (green smaller circles).

3.4 Source searching

The dataset 544_0147511601 was processed with both SAS19 and SAS20, 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 sources with likelihood of detection, DET_ML$\geq$ 25, to be detected.
We found 146 sources with SAS19 and 147 sources with SAS20 (Fig. 4).
The positions were found to be consistent, with differences between 1 and 5 arcsec.
All sources found in SAS19 are also found in SAS20; one source is found in SAS20 and not in SAS19: however, the likelihood of detection is near the threshold, DET_ML_20 = 25.999336, DET_ML_19 = 23.12259 (threshold=25; Fig. 5).

The distributions in counts are consistent (Fig. 6).

Finally, the classification as extended source obtained with the two distributions is consistent.

4 Validation results: New and updated features in SAS 20

4.1 Test of RGS and EPIC observations with repeated frames problem

This problem was finally resolved at the ODF creation stage, rather than in the SAS and was withdrawn from the validation.

4.2 Specific OM updates

It was demonstrated that Omichain and associated tasks that are run within omichain now correctly include the expected comments.

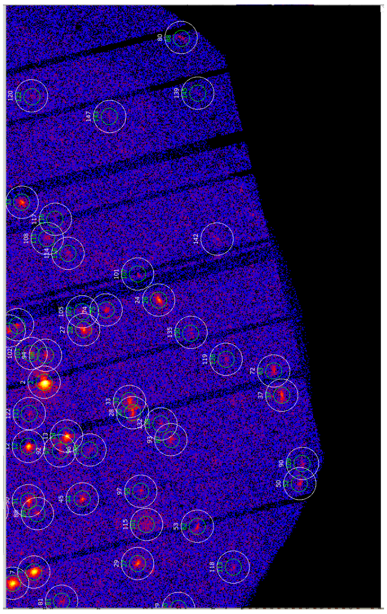

Figure 5: Zoom showing the only difference in detection (src142 from SAS20)

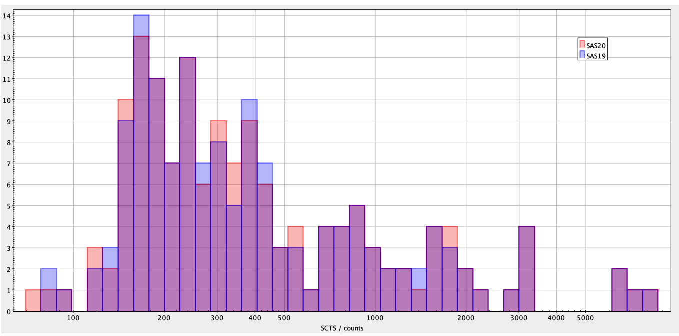

Figure 6: Histogram of the counts distribution of the sources found in SAS 19 (purple) and SAS 20. (pink)

4.3 Combine spectra from different cameras over different energy ranges

The new functionality in especcombine was tested by combining spectra from MOS and pn using the standard channel ranges (MOS: 0-11999, pn: 0-20479). Response matrices were created over the energy range 0-12 keV (MOS) and 0-15 keV (pn). It was confirmed that the disparate energy ranges produce identical results to when the response matrices are created with the same energy limits for each instrument, i.e. 0-12 keV.

4.4 Produce QPB products

The task qpbselect was ran on the observation 0147511601, which is EPIC-pn in FF mode, to produce products that can be used to remove instrumental noise for epic-pn. This task is an extension of evqpb as it includes for pn the use of NDSLIN.
The following sequence of tasks was run

```
# Produce Image

evselect table=0544_0147511601_EPN_S003_ImagingEvts.ds expression='#XMMEA_EP
&& (FLAG==0) && (PATTERN<=4)' imagebinning=binSize imageset=PNimage.ds
withimageset=yes xcolumn=X ycolumn=Y ximagebinsize=80 yimagebinsize=80

# Run qpbselect image

qpbselect table=0544_0147511601_EPN_S003_ImagingEvts.ds attfile=0544_0147511601_AttHk.ds
productname=PNimage.ds outprod=QPBPN_image.ds

# Produce src spectrum

evselect table=0544_0147511601_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(25738.907,18837.907,1200))'

# Run qpbselect on src spectrum

qpbselect table=0544_0147511601_EPN_S003_ImagingEvts.ds attfile=0544_0147511601_AttHk.ds
productname=PNsource_spectrum.fits outprod=QPBPN_spectrum.ds
```

The documentation says 'productname' is not mandatory which is not true. This needs to be fixed. The qpbselect image and spectrum command run succesfully and produce two files: QPBPN_image.ds and QPBPN_spectrum.ds.

4.5 RGS background smooth technique

This update was withdrawn from the SAS 20 public release and was not validated here.

4.6 Sensitivity maps in units of flux

The new version of `esensmap` giving the option of sensitivity maps in units of flux was integrated into the pipeline and found to run to completion.

4.7 Fix EPIC-pn Filter problem

Observation 0820310401, which exhibited a reduction in temperature of the EPIC-pn camera, was tested with SAS 19.1 and SAS 20, running the odfingest and epproc tasks.
With SAS 19.1, the processing produced an event file, 3442_0820310401_EPN_U014_ImagingEvts.ds, with the FILTER set to *CalThick*. Using SAS 20 the FILTER keyword in this same file is set to *Thick* as it should be.

4.8 Test Absolute Effective Area correction

The correction was tested on the galaxy cluster, Abell0133, OBSID=0723801301, following the procedure:

1. Process the ODF
2. Generate calibrated EPIC eventlists
3. Filter events and remove high background
4. Create images and select source and background regions
5. Run arfgen with applyabsfluxcorr=no (default)
6. Run arfgen with applyabsfluxcorr=yes
7. Fits MOS1, MOS2 and PN spectra independently, using the apecmodel (XSPEC) with the two ARF files and compare.

A difference in effective areas was found between the two runs of arfgen consistent with the absolute effective area arrays contained in the test CCF, XRT3_XAREAEFF_0014.CCF.

4.9 Barycen solar system ephemeris

1. It is confirmed that barycen now accepts solar system ephemeride files, other than DE200.
2. Analysis of the Crab pulsar data from observation 0811024101 using DE200 and DE430 yields a mean difference of barycentrically corrected times of 0.001018s.
3. The code correctly includes the keyword PLEPHEM in the primary and event list headers of the corrected event list file.

5 Validation results: Python support

Python support was tested and code updates made to correct the problems found.

5.1 pysas: testing SAS python threads from notebooks and CLI

5.1.1 sas-startup from a python script

The SAS python tool *startsas* was tested with the script startsas_test1.py, with the following results:

- An issue was found with downloading data from the archive when running the script with python 3.8.x. This was resolved by changing to python 3.9.
- The logging from startsas was initially stored in the folder where startsas is run from even if the user has explicitly set a different workdir.

  This was fixed such that the directory containing the log file can be selected. A separate logfile can be selected for each run.
- Running startsas for a number of obsids from the same folder produced a startsas.log file with the appended outputs from all the different runs. This created problems when startsas tries to identify the correct summary file.

  This was resolved so that different ODFIDs are not mixed together in the same log file.
- The option to pass in cifbuild options via the cifbuild_opts parameter was not working. Documentation specified that cifbuild_opts should be a string but examples are needed.

  This was fixed for SAS 20.

5.1.2 sas-startup thread

Following the steps from the thread worked well (note the notebook uses conda environment with python 3.9).

5.1.3 epic-reprocessing

Following the steps, all worked well.

5.2 Packages migrated to Python

The python versions of the packages ombackground, omdrifthist, rgsimplot and rgsspecplot were tested. Differences were found in the output from these tasks compared with the original Fortran or C++ equivalents. Based on this it was decided that the Python versions are not yet ready for release within SAS 20.
Python versions of the slew processing tasks, eslewchain and eslewsearch were tested and compared with the original Perl scripts. The output showed some differences, which while not major showed that more work is needed to fully validate these tasks. The introduction of these will be postponed to a future SAS release.

6 Conclusion

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

- evqpb (v0.10.1)

The SAS scientific validation process concluded that SAS 20 was validated and should be released.

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