XMM-Newton (cross-)calibration

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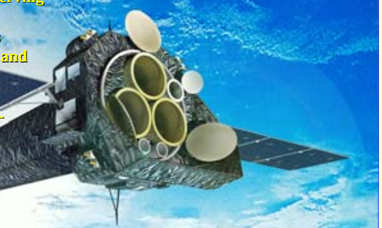
XMM-Newton

- Launched December 1999
- 3 Wolter type 1 telescopes
- 3 instruments: EPIC, RGS, OM
- Instruments operated in parallel
- 48-hour high elliptical orbit



European Photon Imaging Camera:

- spatially resolved spectroscopy over the field-of-view of 30' with a moderate energy resolution (E/Δ E=10-50 in 0.1-15 keV)
- 3 independent cameras (2 MOS & 1 pn), observing simultaneously the same field
- 3 different light filters for both camera types
- Different modes to accommodate brightness and timing
- pn: 12 back illuminated pn-junction CCDs
- MOS: 7 front illuminated Metal-Oxide Semi-conductor CCDs

Reflecting Grating Spectrometers

- high-resolution spectroscopy of bright sources in the energy range from 0.3 to 2.1 keV

Optical Monitor

- extends the spectral coverage of XMM-Newton into the UV and optical
- six broad band filters allow
- two grisms, one in the UV and one in the optical

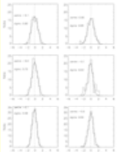
EPIC calibration status

Improvements in EPIC Calibration:

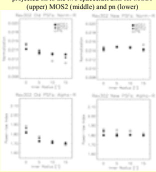
- **Vignetting:** Differences in flux for off axis sources for each camera are reduced from ± 14 % to ± 5 %.
- **Astrometry:** Absolute Pointing Accuracy: 1.0" (r.m.s.), Relative astrometry within each camera 1.5" (r.m.s.), Relative astrometry among all three EPIC cameras 1.5"
- **PSF:** Consistent spectral fits for various different annular extraction regions such as they are used in the analysis of piled-up sources.
- **MOS Low Energy:** Change in the low energy redistribution characteristics of the MOS cameras with time modelled in DRM (see S. Sembay these proceedings)
- **MOS Gain/CTI:** Reduced the uncertainty in the energy calibration from 10 to 5 eV for the imaging modes of the MOS cameras. MOS Timing mode energy accuracy agrees with the imaging modes within 0.3 %.

Important ongoing calibration topics:

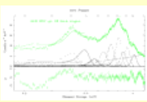
- **PN CTI:** Small Window mode currently shows a Gain/CTI under correction of ~2-3 % most prominent around the O-edge. The internal calibration source shows an over correction of up to 15 eV at Mn-K in pn Extended Full Frame mode.
- **PN redistribution:** Spectral response below about 400 eV might not yet be correctly reproduced. EPIC-pn spectra show an excess below 500-1000 eV of about 20 % in SW mode. Current investigations point in the direction of a redistribution problem above the O-edge. On-going work on the pn redistribution is expected to bring down the discrepancy below 10%.
- **EPIC-MOS** cameras show for energies above 3keV an **excess** up to 15 % with respect to EPIC-pn that might be related to various system components and is under investigation.



Histogram of the distribution of offsets for each EPIC camera with respect to the 2MASS reference frame projected on to the two spacecraft axis for MOS1 (upper) MOS2 (middle) and pn (lower)



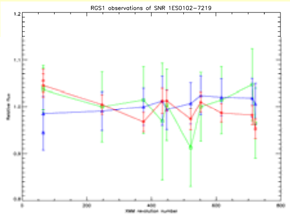
Fitted normalization (top) and power-law index (bottom) vary as a function of extraction region (left to right: 0-30" circle, 5-40" annulus, 10-50" annulus, 15-60" annulus), using the old CCF PSFs (left) and the new CCF PSFs (right) for the MCG-06-30-15.



zeta puppis EPIC pn with redistribution SAS6.0

RGS calibration status

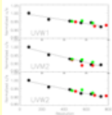
- **Stability of the RGS:** The responses of both RGS1 and RGS2 have remained stable throughout the mission
- **RGS Wavelength Scale:** Typical 1 sigma errors of about 7mÅ. While this is a relatively small fraction of the instrumental line width it is clear that the errors are dominated by a systematic component whose origin is under investigation. When brought under control, wavelength measurements should approach the level of the statistical errors which with the RGS's effective area can be as small as 1mÅ.



Relative flux observed in soft (red), medium (blue) and hard (green) energy bands below the silicon edge of the SNR 1ES0102-7219 in RGS1 up until the end of the fourth year of operations.

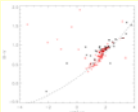
- **Small-scale features in RGS spectra:** The RGS detectors show well-documented Oxygen absorption near 23Å in the effective area model and a weaker feature from Fluorine near 18Å is taken into account in the latest calibration release. In work of this type, comparison of RGS1 and RGS2 is a worthwhile check, where possible, in order to identify low-level misbehaviour of mildly cool or warm CCD pixels or columns. Recent progress has brought a degree of control over systematic errors of this type with the introduction in SAS v6 of the choice of applying individual pixel offset corrections as an alternative to the usual node-based corrections.

OM calibration status



The normalized count rates of OM as a function of time in UVW1, UVM2 and UVW2 filters, for three white dwarfs, BPM16274 (black), Hz 2 (red), GD153 (green).

Zero points and in-flight throughput: 10 % degradation during 4.5 year operations. For the three optical filters (UBV), the degradation is smaller, about 5 % over the whole time.



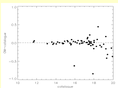
Comparing the observed UV color-transformation for two fields, SA95 (red) and G153 (black), with the simulated one (dashed line).

Photometry

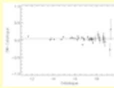
- UBV colour transformations from the OM to Johnson's system established based on observations. The colour-transformations for UV filters are based on the simulations.
- Testing OM photometry with external catalogues: A Landolt standard star field (SA95) has been observed with OM at rev. 407 and rev. 759. OM magnitude is in very good agreement with the Stetson's catalogue magnitude in rev. 407, but there is an offset of 0.04 mag in rev. 759 due to zero point degradation. A time-dependent count rate correction will be added into the Current calibration files (CCF).
- OM photometric accuracy is 2.3 %.

Grisms:

- Several spectrophotometric stars and F-type stars have been observed to establish the wavelength and flux calibration of both Visible and UV grisms.
- Tools to extract and calibrate the spectra wit SAS 6.0. The main source of error in the grism wavelength scale is due to the determination of the centroid of the zero order, which can produce a shift of 10 Angstroms.
- The accuracy of the grisms flux calibration is about 10 %.



The difference in standard V magnitude between Stetson's measurement and OM measurement for Landolt standard star field SA95 in rev. 407 (left) and rev. 759 (right).]



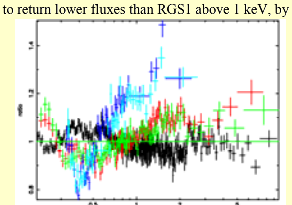
Cross calibration

Method

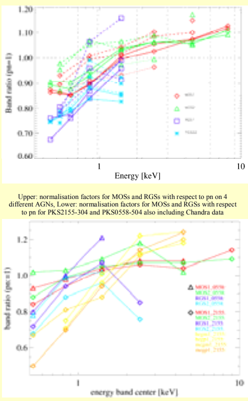
- Various types of sources like AGN, SNR, stars, neutron stars
- For smooth continuum sources, the model was initially based on EPIC data and subsequently fitted simultaneously with the RGS
- For line-dominated sources such as coronae and SNRs a phenomenological model has first been built of continuum and as many lines as needed to reproduce well the RGS before fitting simultaneously with EPIC
- A further approach for some sources was to use the RGS fluxed spectrum as a model input.
- The normalisation of all instruments is done with an additional multiplicative constant where the pn constant is set to 1. In XSPEC terminology: model=const*(any_number_of_model_components)
- The following six energy bands have been adopted to investigate the energy dependency of the normalisation between instruments:0.35-0.7 keV, 0.7-0.972 keV, 0.972-1.84 keV, 1.84-3.0 keV, 3.0-6.0 keV, 6.0-12.0 keV.

Results on AGN

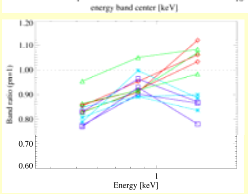
- 0.2-12keV: EPIC MOSs are in relatively good agreement with pn, with a global normalisation very close to 1, within 2-3 %, slightly below for MOS1 and slightly above for MOS2
- MOSs show a trend for flatter spectra. However the power law indices of EPICs are consistent within errors in the range 1-10 keV (ΔΓ < 0.07). The MOS/pn flux difference in the lowest energy bad (0.35-0.7 keV) is on average about 10-15 %. That might be partly attributed to inadequate modelling of the pn redistribution at low energies, as in general RGSs tends to agree better with MOSs.
- But the discrepancy is rather variable and source dependent: for some sources the agreement is very good at low energies. For instance a good agreement is observed between MOS1 and pn on E1821+643. On other sources the discrepancy increases to up to 15 %, in the 0.35-0.7 keV band. An extreme case in our analysis shows the AGN MCG-6-30-15 where the pn excess in the energy band 0.35-0.7 keV is 20 %. The agreement tends to be better for faint sources, suggesting that pattern pile-up, or x-ray loading (in the pn offset maps) or a "lower threshold effect" for pn could be at play.
- MOS2 shows a systematic higher normalisation factor of about 5 % relative to MOS1 below 2 keV, possibly pointing to a real effective area effect.
- RGSs display in general a 20 % lower flux than EPICs in its energy range 0.35-1.84 keV. But as the discrepancy is higher in the lowest energy band (0.35-0.7 keV), RGSs tends to return systematically harder spectral slopes. However for some sources the agreement with MOSs is very good above 0.5 keV, for instance in the MCG-6-30-15 case.
- RGS2 tends to return lower fluxes than RGS1 above 1 keV, by about 10 %.



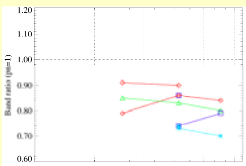
Ratio of data and model of simultaneous spectral fits to PKS2155-304. Black: pn, red, MOS1, green: MOS2, dark blue: RGS1, light blue: RGS2. Also here the new PSF correction improved the overall normalization from ± 12 % to ± 5 %. The larger residuals below 600 eV are due to uncertainties arising from the complicated shape of the redistribution function and the low energy effective area in combination with a gain problem of the pn-SW mode that is currently under investigation. Above 7 keV the residuals probably arise form uncertainties in the background subtraction method.



Upper: normalisation factors for MOSs and RGSs with respect to pn on 4 different AGNs, Lower: normalisation factors for MOSs and RGSs with respect to pn for PKS2155-304 and PKS0558-504 also including Chandra data



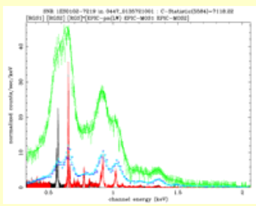
1ES0102-7219 observation from revolution 447 normalisation factors for MOSs and RGSs with respect to pn in different energy ranges
Black: RGS1, red: RGS2, green: pn, dark blue: MOS1, light blue:



Normalization constants from different energy bands for the analysed isolated neutron stars from MOS1, MOS2, RGS1, RGS2

Results on SNR

- SNR 1ES0102-7219 RGS data were selected from the whole RGS detector with backgrounds synthesised from long-exposure blank fields according to the time-variable background rate monitor. EPIC source data were also selected from the whole of the projection of the RGS detectors onto the EPIC focal planes. This SNR's spectrum is unusually simple: because of an apparent total absence of Fe lines, a spectrum can be successfully modelled with 37 lines from CVI, OVII, OVIII, NeIX, NeX, MgXI and MgXII of which the O and Ne lines are particularly strong. With the RGS line positions and widths fixed empirically according to the RGS spectrum, a set of best fit line fluxes is calculated modulated by constant factors for each instrument in the four relevant XMM energy bands.
- The lines in EPIC-pn (FF) and EPIC-pn (LW) data both agree quite well with the RGS model lines as regards line position and width, although they clearly disagree slightly with each other: the RGS lines lie between LW and FF. As judged by the fit C-statistic, LW is marginally better. The SW data, on the other hand, have clearly been shifted to lower energies by about 20 eV. This indicated a CTI under-correction that has been improved meanwhile. As far as EPIC-MOS is concerned, the measured emission line profiles are more peaked than the corresponding redistribution model suggests. RGS errors are typically 1 % and MOS errors 0.5 % respectively. The energy band ratios are rather consistent with the AGN analysis, showing the same systematics.
RGSs fluxes:
15 % lower than pn in the 0.35-1.84 keV band;
20 % lower in the 0.35-0.7 keV band;
MOSs fluxes: ~10-15 % lower than pn in the 0.35-0.7 keV band.



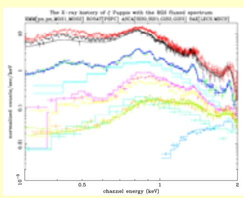
1ES0102-7219 observation from revolution 447 spectral fitting, with pn in large window. Black: RGS1, red: RGS2, green: pn, dark blue: MOS1, light blue

XMM-NEWTON VERSUS OTHERS

- Folding the RGS fluxed spectrum of the constant star ζ Puppis through the detector response matrices of other instruments allows a direct comparison between them. The figure below shows the spectra derived without any renormalization or other adjustment for XMM-Newton, ROSAT, ASCA and SAX. These RGS spectra are mostly quite successful in reproducing most of the measurements with the exception of the EPIC-pn at low energies.

Isolated Neutron Stars

- Two isolated neutron stars (INS), RXJ0806.4-4123 and RXJ0720.4-3125 have been analysed. The absorbed black body model is a reasonable representation of the INS observations. Thus the model we use here for spectral fitting is const*wabs*bb, where const is the normalisation factor for each instrument. RXJ0806 is relatively faint and there are not enough counts in the energy band 0.7-0.972 keV. The difference of normalisation of the MOSs and RGSs with respect to pn is about 20 %.



Folded the RGS fluxed spectrum through various detector response matrices. From top to bottom pn (medium filter), pn (thick filter), MOS1&2, ROSAT PSPC, ASCA SIS0&1, ASCA GIS2&3, SAXLECS&MECS

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