EPIC CALIBRATION (ANECDOTES)

FROM 3 YEARS BEFORE TILL 6 YEARS AFTER LAUNCH

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ABSTRACT

XMM-Newton has been extensively calibrated on ground and in orbit. The main calibration phase lasted from 3 years before launch up to now and is still ongoing. We will review the general approach of calibrating a CCD technology based X-ray camera taking into account all major calibration steps and improvements until now. This includes an overview of the calibration strategy for various physical phenomena regarding X-ray CCDs and the way we chose to organize those in calibration software and data files.

Furthermore we like to present some lessons learned throughout the whole calibration process that may be of use for future experiments to be calibrated. Note that the 'anecdotes' have only been given during the talk and are considered 'impossible' to be transformed into the paper.

1. THE XMM-NEWTON EPIC CAMERAS

XMM-Newton (Jansen et al. 2001) was launched in December 1999 on an Ariane 504 rocket from French Guyana. Its six instruments are operated in parallel through the course of a 48-hour highly elliptical orbit. Three Wolter type-1 telescopes with 58 nested mirror shells focus X-ray photons onto the five X-ray instruments comprising the European Photon Imaging Camera (EPIC) (Strüder et al. 2001, Turner et al. 2001) and the Reflecting Grating Spectrometers (RGS) (den Herder et al. 2001). The Optical Monitor (OM) (Mason et al. 2001), employing a 30 cm Ritchey Chrétien optical telescope, can perform parallel optical observations of the same field.

EPIC is comprised of three cameras employing two distinct detector technologies. The two EPIC-MOS cameras use front illuminated EPIC-MOS (Metal-Oxide Semi-conductor) CCDs as X-ray detectors, while the EPIC-pn camera is equipped with an EPICpn (p-n-junction) CCD. Both have been specially developed for XMM-Newton. EPIC provides spatially resolved spectroscopy over a field-of-view of 30' with moderate energy resolution. The EPIC cameras can be operated in various observational modes related to the specific readout strategies in each mode. For a detailed description of the modes see Kendziorra et al. (1997), Kendziorra et al. (1999), Kuster et al. (1999) and Ehle et al. (2003). The RGS is designed for high-resolution spectroscopy of bright sources in the energy range



Figure 1: The EPIC-pn (upper) and EPIC MOS (lower) focal planes

from 0.3 to 2.1 keV. The OM extends the spectral coverage of XMM-Newton into the UV and optical, and thus opens the possibility to test physical models of source spectra against data over a broad energy. The six OM filters allow colour discrimination, and there are two grisms, one operating in the UV and one in the optical, to provide low-resolution spectroscopy.

2. GENERAL APPROACH OF CALIBRATING A CCD TECHNOLOGY BASED X-RAY CAMERA (EPIC)

The first plans for EPIC calibration have been started in June 1995 with the system calibration document by the 'XMM system calibration team' that outlined the principle calibration topics and first ideas how to proceed with the calibration. Then various phases of calibration have been carried out starting always from first measurements at the individual small test facilities at the PI institutes leading then to major calibration campaigns at the facilities mentioned later. It is difficult to give a sharp step where development ends and where calibration starts. However we consider the mainstream of calibration only as the calibration campaigns with the fully integrated instruments.





Figure 2: The two most important ground calibration facilities for XMM-Newton: Upper: the PANTER test facility at Neuried/Munich. Lower: The Orsay LURE synchrotron

In principle calibration is divided up in ground and in orbit calibration where on ground the main calibration of all system components is done with a still virginal system. No time dependence measurements are possible per definition since the instruments are not exposed to environments that change their behaviour.

After launch the ground calibration needs to be verified and possibly refined for the first orbit changes or unexpected behaviour. As of launch the system is now exposed to orbital environment (radiation, temperatures, low pressure...) and needs to be monitored carefully in order to track time variability.

2.1 Ground calibration

The major part of the EPIC ground calibration has been carried out at the PANTER test facility at Munich and the LURE synchrotron at Orsay near Paris. For EPIC-pn ~ 4300 man-hours in calibration plus 4 persons maintaining the test facility and 5 people that integrated the instruments at the test facilities various times have been spent. For the EPIC-MOS the number for the actual calibration was higher by a factor of two since more cameras had to be calibrated.

3. CALIBRATION STRATEGY FOR VARIOUS PHYSICAL PHENOMENA REGARDING X-RAY CCDS

We highlight in the following some of the XMM-Newton EPIC calibration topics and their treatment. Details can be found in the regular updated 'EPIC Status of Calibration' document at the XMM-SOC calibration pages and in the CCF release notes.

3.1 Imaging

The PSF is the spatial distribution of light in the focal plane in response to an observed (monochromatic) point source. The PSF integrates to 1 over the infinite focal plane.

Measurements at PANTER for various monochromatic lines in combination with simulations using SCISIM and various in orbit source measurements have been used to derive an analytical model of the PSF with a King function.

After launch problems with ground calibration concerning spectral shape and normalization of spectra for different extraction regions have been encountered and a refinement of the parameters of the PSF using the Active Galaxy MCG-06-30-15 was performed.

3.2 Effective area

The effective area is the collecting area of the optical elements and detector system of the EPIC cameras as a



Figure 3: EPIC-MOS effective area for various filters

function of energy. It is a combination of the collecting area of mirror, the transmission of the gratings (for the MOS), the filter transmission, the Quantum Efficiency of CCDs, and the Vignetting of the whole system.



Figure 4: Vignetting campaign with various observation of the SNR 3C58 to determine the exact position of the optical axis of the telescopes

Mirror effective area measurements have been performed at PANTER for all mirror modules. The thick filter throughput was measured at Bessy and the thin and medium filters have been calibrated at the Osservatorio Astronomico di Palermo. Long measurements for QE for various monochromatic lines have been carried out at PANTER and in addition edge scans for Si and Au have been performed at the LURE synchrotron at Orsay.

After launch the EPIC-pn-QE needed some refinement due to a different thickness of wafer and SiO_2 layer than originally assumed.

The mirror parameters have also been refined around edges using very bright sources that gave a much higher statistical accuracy in comparison to that we could reach with our ground measurements.

The vignetting needed a recalibration since the optical axis turned out to be at a not exactly determined position. For that campaign we used various pointings of the SNR 3C58.

3.3 Energy redistribution

The energy redistribution is the energy profile recorded by the detector system in response to a monochromatic input. It is mode and time dependent and difficult to treat especially at low energy where one is facing a large interplay between redistribution and effective area.

Very long measurements had to be performed at PANTER for various monochromatic lines and also edge scans at LURE for Si and Au could be used to exactly model the spectral response behaviour.

It should be mentioned here that due to a failure of the EPIC-pn flight model during a thermal vacuum test the EPIC-pn flight spare unit had to be used finally on XMM-Newton. This unit had not undergone an as deep calibration assessment like the flight model especially on redistribution matters, since those measurements are



Figure 5: EPIC-pn response to monochromatic Cu-L ground calibration source

very time consuming and could not be repeated for the flight spare model completely due to time constraints facing the launch of XMM-Newton. For that reason we expected to refine especially for the EPIC-pn the redistribution parameters in orbit. This was done using various Blazars and the isolated neutron star RXJ1856-3754.



Figure 6: Spectral fit of the EPIC-MOS1 camera before (black) and after (red) correct treatment of the time and spatial dependent response matrices

The MOS cameras needed a special treatment with a combination of time and spatial dependent redistribution due to evolving patch at the boresight position of the focal CCDs (Read 2005).

3.4 Gain/CTI

CTI (Charge Transfer Inefficiency) is the imperfect transfer of charge as it is transported through the CCD to the output amplifiers during read-out. The Charge Transfer Efficiency (CTE) is defined as 1-CTI. Gain is the conversion (amplification) of the charge signal deposited by a detected photon, from ADU (Analogue to digital unit) charge into energy (electron-volts).



Figure 7: In orbit energy calibration with the line rich SNR Cas-A for EPIC-pn

The same measurements as for effective area and redistribution properties for various monochromatic lines could be used to determine the Gain and CTI properties of the EPIC cameras. In addition we used some measurements with a fluorescence tube at LURE for the energy calibration of the fast EPIC-pn modes.

For the same reason as in 3.3 this calibration needed to be refined in orbit, and the original values had to be refined for the flight spare model using line rich SNRs N132D and Cas-A. The time dependent CTE degradation in orbit due to particle radiation is monitored with the internal calibration sources (Al-K and Mn-K lines) and updated accordingly (Harbarth 2005).

3.5 Timing

Chopper measurements down to 1 ms Period carried out by the University of Tübingen and the PANTER facility have been the basis for the EPIC-pn timing calibration.

After some debugging of the *barycen* code after launch the EPIC-pn Timing accuracy is monitored regularly using the Crab and other pulsars and comparing the XMM-periods with radio data (Caballero 2005).

3.6 Background

Long CLOSED measurements at PANTER and CLOSED measurements in orbit in combination with various BG models for particle radiation, internal and astrophysical background provide the basis for the treatment of the EPIC background. Currently EPIC is putting strong effort to provide the community with improved tools to treat the EPIC background in the appropriate way.

4. ORGANIZATION OF CALIBRATION SOFTWARE AND FILES

The XMM-Newton calibration is organized by the Science Analysis System (SAS) and the so called Current Calibration Files (CCF). Processing XMM-Newton data, the user will need both the SAS and the CCFs in order to create event files that are up to date regarding the newest calibration knowledge. Operated on an individual observation the SAS will check locally the available calibration information and pick out the most up-to-date calibration combination applicable for the data to be processed.

Saying that it is absolutely recommended to the user to check for SAS and CCF updates as often as possible, best with an automated procedure (as it is explained at the XMM-SOC web-pages). The philosophy of SAS and CCF is the following: the SAS contains all calibration-code necessary to correct the data and the CCF files contain the parameters needed by the calibration code.

Usually a SAS update is provided every year, while CCF updates can be expected every day, when new calibration knowledge is available to the instrument teams. This provides a very flexible system that allows the calibration team to transfer the latest calibration knowledge very fast to the community. Every new or updated CCF is explained by a Release Note that is available from the XMM-SOC web site and allows the user to judge if the calibration update is relevant for her/his data analysis and if so reprocessing of data is required.

5. MAJOR CALIBRATION STEPS AND IMPROVEMENTS

The following list gives a chronological list of major improvements of the calibration. Details on all topics can be found in the calibration Release Notes at the XMM-Newton SOC pages or in the various publications on XMM-Newton calibration.

- 1997-2000: Ground calibration PANTER, Orsay, Bessy, University of Tübingen
- 1998 February- October: Main phase of ground calibration
- Launch 10.12.1999
- 19.01. 16:19 h first light EPIC-pn
- 21.01. 15:11 h first light EPIC-MOS
- 2000 Feb-June: CAL-PV-phase
 - o 22 calibration targets
 - o 29 performance verification targets

- CTE in-orbit calibration refinement and RMF tuning
- EPIC-pn offset calculation method changed
- 2001: EPIC-pn fast modes energy calibration refinement
- 2002:
 - o relative timing problem solved
 - EPIC-MOS CTE degradation requires epoch dependent energy calibration
 - further down-cooling of the MOS cameras to slow down degradation process
- 2003:
 - vignetting recalibration (optical axis)
 - o major cross calibration campaign started
 - EPIC-pn QE refinement
- 2004:
 - o recalibration of PSF
 - recalibration of astrometry
- 2005:
 - discovery of spatial and time-dependent redistribution change in both MOSs \rightarrow epoch and spatially dependent RMFs
 - recalibration of EPIC-pn effective area and RMF
 - micro-meteoroids (see A. Abbey these proceedings)

6. LESSONS LEARNED

Calibration seems to be a never ending story about learning lessons. Trying to motivate future calibrators to perform good calibration we like to stress here some points of the calibration where future missions may learn from the experience of XMM-Newton.

We consider the ground calibration as very intense and important task for the whole calibration process and recommend to carefully plan, execute and document that process. Given the fact that ground calibration information may be still useful and needed more than 10 years after the actual measurement it is crucial to transfer that knowledge from one calibration generation to the next for missions with such a long planning and life time like XMM-Newton.

Also we see the cross calibration of different cameras and camera models as a very important issue where future missions may already improve before launch. We know that this statement is perhaps too optimistic given the time and man power constraints in such calibration campaigns, but where possible cross calibration measurements are recommended as early as possible.

The in orbit calibration and monitoring of the evolution of the cameras is a very important the quality of the calibration driving factor. We recommend to carefully prepare an in orbit calibration plan that should be discussed very much in advance of the launch of the instruments. Understanding that fighting for calibration time in competition with the scientific observations which are of course the more important once is a tough job, we recommend keeping the pressure for the need of regular and non regular calibration observations. Only a good set of calibration observations can guarantee a successful scientific performance of the observatory.

In addition we see the strong need for a set of standard calibration sources for the X-ray regime. Given the luxury of having 6 satellites (XMM-Newton, Chandra, RXTE, Swift, Integral, Suzaku), that have X-ray instruments as their payload, in orbit simultaneously and for the coming years, we strongly recommend to form an international calibration group that may steer the cross-calibration efforts in this field.

7. AKNOWLEDGEMENT

The calibration of the XMM-Newton EPIC instruments is performed by the EPIC consortium in collaboration with the XMM-Newton SOC at the European Space Astronomy Center. We like to thank all involved persons participated in the EPIC calibration that dedicated and still dedicate major parts of their work to the benefit of the calibration knowledge of EPIC and hope that the fruitful collaboration will carry on for the next 9 years to come.

The XMM-Newton project is an ESA Science Mission with instruments and contributions directly founded by ESA Member States and the USA (NASA). The German contribution of the XMM-Newton project is supported by the Bundesministerium für Bildung und Forschung/Deutsches Zentrum für Luft- und Raumfahrt. The UK involvement is funded by the Particle Physics and Astronomy Research Council (PPARC).

8. REFERENCES

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9. ANNEXUS: CALIBRATOR SNAPSHOTS

