COMPARISON OF XMM-NEWTON EPIC, CHANDRA ACIS-S3, ASCA SIS AND GIS, AND ROSAT PSPC RESULTS FOR G21.5-0.9, 1E0102.2-7219, AND MS1054.4-0321

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ABSTRACT

This paper presents a “man on the street” view of the current status of the spectral cross calibration between the XMM-Newton EPIC, Chandra ACIS-S3, ASCA SIS and GIS, and ROSAT PSPC instruments. Using publicly released software for the extraction of spectra and the production of spectral redistribution response matrices and effective areas, the spectral fits of data from three astronomical objects are compared. The three sources are G21.5-0.9 (a heavily absorbed Galactic SNR with a power law spectrum), 1E0102.2-7219 (a SNR in the SMC with a line-dominated spectrum), and MS1054.4-0321 (a high redshift cluster with a thermal spectrum). The agreement between the measured fluxes of the various instruments is within the ±10% range, and is better when just XMM-Newton and Chandra are compared. Fitted spectral parameters are also in relatively good agreement although the results are more limited.

Key words: Missions: XMM-Newton, Chandra, ASCA, ROSAT – calibration: cross calibration

1. INTRODUCTION

In all X-ray observatory missions a great deal effort goes into the calibration of the scientific instruments with goals of an absolute accuracy usually better than, or much better than 10%, depending on the quantity (e.g., energy scale, relative area, total flux, etc.). The calibrations are usually based on extensive ground calibration data (which are never as complete as one would like) coupled with extensive in-flight observations of celestial objects (which are always problematic as nature has not seen fit to provide ideal calibration sources). In addition, there is the fact that instrument responses can and will vary with time (e.g., the increasing charge transfer inefficiency, CTI, of CCDs). Thus instrument calibration is therefore a long-term endeavor where occasionally the final step is just to declare victory and move on. As a final editorial comment, the astronomical community owes a great debt of gratitude to those individuals who undertake this very difficult task.

But back to the issue at hand, one practical way of examining the reliability of calibrations is to compare the results of various observations of celestial objects using various instruments. This at least provides an estimate of the relative errors between the different instruments. (There is an old joke from the early X-ray missions that nobody has ever measured the spectrum of the Crab as the calibrations of some instruments were fudged to give the accepted results.) While simultaneous observations of the same source by different instruments are ideal, for spectral calibration comparisons independent observations of spectrally constant sources can be substituted. Thus distant supernova remnants and high redshift clusters are the targets of choice. However, there are problematic issues with both types of sources, and nature has not provided convenient “standard candles” for X-ray astronomy. SNRs can have complex line spectra and those in the Milky Way which are small enough in solid angle to be useful are distant and therefore heavily absorbed. High redshift clusters are not particularly bright so the photon statistics can be quite limited.

This paper will present results from three sources which provide useful results but all suffer from limitations noted above. They are: 1) The Galactic SNR G21.5-0.9 which is heavily absorbed but provides a constant power law spectrum visible from $\sim 1 - 10$ keV. 2) The SMC SNR 1E0102.2-7219 which suffers relatively little absorption but has a soft, very complicated, and line-rich spectrum. 3) The high redshift cluster MS1054.4-0321 which also suffers little absorption, has a relatively simple thermal spectrum, but has limited photon statistics. Not all instruments have observations of all of the sources, which is another limitation for this study.

2. DATA REDUCTION AND ANALYSIS

To provide the pedestrian’s view of the current status of the cross calibration, only publicly released software and calibration data files have been used for this work. For XMM-Newton EPIC data, SAS V5.2 [http://xmm.vilspa.esa.es/user/sas_top.html] has been used to extract source and background spectra, create the spectral redistribution matrices (RMFs), and create the ancillary region files (ARFs, effective area vectors). For Chandra ACIS-S3 data, CIAO 2.1 [http://asc.harvard.edu/ciao] was used with occasional help from the scripts of Keith Arnaud. Spectra for ASCA GIS and SIS data as well as...
ROSAT PSPC data were extracted, and RMFs (where necessary, otherwise standard RMFs from the public calibration data base were used) and ARFs were created using the HEASoft software package (ftp://legacy.gsfc.nasa.gov/). In all cases, Xspec was used to fit the data after grouping for statistical purposes using grppha (Xspec and grppha are also part of the HEASoft software package).

3. The Cross Calibration

3.1. G21.5−0.9

Figure 1. XMM-Newton EPIC MOS1 image of G21.5-0.9 from the Science Validation observation.

G21.5-0.9 is a Galactic SNR consisting of a Crab-like bright inner region and a fainter but clearly visible X-ray halo (Figure 1). (Note, for some of the “science” of this source, see the poster papers in these proceedings by La Palombara and Mereghetti, and Bocchino and Bandiera.) Data for this source are available from all instruments, although the ROSAT PSPC observation is of limited utility because the source is so heavily absorbed. Because of the relatively poor angular resolution of the ASCA instruments, extraction regions large enough to include the entire remnant were used (165′′ extraction radii for XMM-Newton, Chandra, and ROSAT data and 240′′ for the ASCA data). Source and background spectra were extracted for all instruments.

The data were fit over the 0.5–10.0 keV energy range with variation in the endpoints due to the individual spectral responses of the various instruments. A simple absorbed power law spectrum was first fit simultaneously to the data with only the overall normalization being allowed to vary between the various instruments. The fits are displayed in Figure 2. While the fits are a bit rough below 1 keV, at higher energies they look quite good. (At energies below 1 keV interstellar absorption has removed most X-rays from the spectrum so what are typically detected are events which have lost some of their energy due to incomplete charge collection by the CCDs and electronics.) The fitted values for the relative fluxes (scaled to the av-

Figure 2. Spectral fits of the G21.5-0.9 data. The color coding is listed on the plot as are the fitted fluxes in the 2–10 keV band and the relative normalizations for the different instruments (the PSPC results are not shown but are listed in Table 1).

Figure 3. Confidence contours for the spectral parameters for fits to the G21.5-0.9 data. The color coding is listed on the plot (the PSPC results are not shown). For this plot the EPIC data, GIS data, and SIS data were fit together to improve the statistical precision.
average value) are in good agreement and range from 0.89 (ROSAT PSPC) to 1.07, with EPIC and ACIS-S3 values in the range 1.00 to 1.07.

Figure 4. Confidence contours for the spectral parameters for fits to the MOS1, MOS2, PN, and ACIS-S3 G21.5-0.9 data. The color coding is listed on the plot.

Figure 3 shows the confidence contours for the fitted values of the power law index and absorbing column density. The spectral parameters of the EPIC PN and MOS detectors were fit simultaneously only allowing the normalizations to vary. This was also done for the SIS and GIS data to improve the statistics. The average results for the EPIC data are completely consistent with those of the SIS. The ACIS-S3 and EPIC slopes agree but there is a ∼10% difference in the fitted values for the absorption column densities. The GIS and EPIC results for the absorption column densities agree well but there is a difference of ∼0.12 in the fitted values for the slope. Figure 4 shows a confidence contour plot for the EPIC and ACIS-S3 data when the EPIC data are fit independently. The PN and MOS1 values agree well while the MOS2 values are somewhat lower in both slope and column density.

3.2. 1E0102.2-7219

1E0102.2-7219 is a SNR in the Small Magellanic Cloud. It is beautifully resolved in the Chandra data as a shell-like remnant. Its spectrum is soft and line-dominated, and very difficult to model short of fitting a vast number of Gaussians to the data. Unfortunately, it was not feasible to use the PN data from the EPIC observation as the positioning of the source for the advantage of the RGS caused part of the remnant to fall on a gap between the CCDs.

For the fits two absorbed APEC models (see http://heasarc.gsfc.nasa.gov/APEC/) with variable abundances were used. The data were fit over the 0.3 – 2.0 keV band, and the fit was not particularly significant. However, the fits can still be used to compare the relative normalizations. As can be seen in Figure 5 (and Table 1), the relative normalizations range from 0.92 to 1.07, with the values for the ACIS-S3 and MOS detectors ranging from 0.96 to 1.05.

As an aside, note the difference between the energy resolution of ACIS-S3 (green curve in Figure 6) and MOS...
spectra (the black and red curves) due to the differences in the response between backside and frontside illuminated CCDs.

### 3.3. MS1054.4-0321

![Figure 7. XMM-Newton EPIC MOS1 image of MS1054.4-0321 from the GT observation kindly provided by Mike Watson.](image)

MS1054.4-0321 (Figure 7) is a high redshift cluster in a direction of low Galactic column density. The limitation for this object as a good calibration source is its low brightness and therefore poorer statistics. Reasonable data are available for the EPIC MOS and PN, ACIS-S3, and SIS. While the SIS data aren’t particularly useful for constraining the spectral parameters, they do provide a reasonable flux comparison.

Figure 8 shows the spectral fits and relative fluxes for the EPIC, ACIS-S3, and SIS data. For these data an absorbed thermal model (Raymond & Smith 1977) was fit where the abundance was allowed to vary.

For the EPIC and ACIS-S3 data, Figure 9 shows the confidence contours for the fitted values for the temperature and absorption column density. The EPIC data were fit simultaneously to improve the statistical results. The fitted values for the parameters are completely consistent.

### 4. CONCLUSIONS

Table 1 gives a summary of the relative flux normalizations for the simultaneous spectral fits for the three objects. In all cases the full range in the XMM-Newton and Chandra values is better than \( \sim 10\% \), which is fairly remarkable at this early a stage in the missions. When the ROSAT and ASCA data are included the full range is still \(< 20\% \). One consistent systematic difference in the data is that the fluxes measured by the EPIC PN instrument are \( \sim 7\% \) lower than the fluxes measured by the EPIC MOS. This discrepancy is also seen in the results of Griffiths (this workshop) for the hard band, and both his paper and that of Haberl should be noted for their comparisons of the EPIC MOS and PN calibrations.

The cross calibration situation is also fairly good when the rest of the spectral parameters are considered, although the number of useful comparisons are much more limited. The G21.5-0.9 results show that for a hard source the fitted values for the power law indecies are completely
### Table 1. Summary table of relative flux normalizations.

| Object       | MOS1 | MOS2 | PN | ACIS-S3 | SIS0 | SIS1 | GIS2 | GIS3 | PSPC |
|--------------|------|------|----|---------|------|------|------|------|------|
| Band 2.0 – 10.0 keV | 1.06 | 1.07 | 1.00 | 1.03  | 0.95 | 1.01 | 0.93 | 0.95 | 0.89 |
| Band 0.5 – 2.0 keV | 1.05 | 1.03 | –   | 0.96  | 1.07 | 1.00 | 0.92 | 0.98 | 0.99 |
| Band 1.0 – 5.0 keV | 0.97 | 0.98 | 0.92 | 1.03  | 1.07 | 1.02 | –   | –   | –   |

*Flux compared over the 0.5 - 2.5 keV band.

consistent to better than 0.05 (~ 3%) for EPIC, ACIS-S3, and SIS data, and agree to ~ 0.1 when the GIS data are included. The MS1054.4-0321 results for EPIC and ACIS-S3 also show good agreement, but the statistics are much poorer.

**Caveats:** There are a number of caveats which go along with these results. First, the calibrations and software were current as of the end of November, 2001. Both the calibration and the software implementation for Chandra and especially for XMM-Newton are changing with time, almost invariably for the better. Second, a fudge was included for the ACIS-S3 fits with a carbon Kα absorption edge of optical depth 1.0 being added to attempt to account for a recently observed systematic discrepancy in the area calibration. The Chandra CIAO software and calibration data are being modified to include this effect. Third, there are clear sensitivities to the energy range, background selection, spectral model, which data are being fit, and what parameters are being fit simultaneously. But this is expected and one of the challenges in trying to separate the “calibration” from the “science”. Fourth, the Chandra ACIS results are for the S3 CCD only.

As the XMM-Newton and Chandra missions progress, the instrument calibrations will also improve beyond the current levels. With additional data, the identification of systematic discrepancies between the results of various instruments will allow the calibration teams to refine their efforts.

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**References**

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