INTEGRAL CROSS-CALIBRATION STATUS

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ABSTRACT

The status of the INTEGRAL cross-calibration is presented for a standard X-ray astronomy source, the Crab Nebula, as well as for some weaker sources. The relative flux normalization for the different INTEGRAL instruments is discussed together with spectral shape features.

1. INTRODUCTION

After one year of successful operation INTEGRAL has gathered a large amount of scientific data. Deeper performance verification, based on comparison of the scientific results obtained from the individual INTEGRAL instruments and from other missions, now becomes crucial. This poster summarizes the current status of the cross-calibration with respect to spectral shape studies.

2. CRAB

The calibration issues should be studied for a bright, steady X-ray source with a rather simple, well established spectral model. Below we present the comparison of INTEGRAL Crab spectra with the canonical model of the Crab Nebula: an absorbed power law, with spectral index, \( \gamma = 2.1 \), and with a normalization at 1 keV, \( A = 9.7 \) photons cm\(^{-2}\) s\(^{-1}\) keV\(^{-1}\) (Toor & Seward, 1974). The absorption hydrogen column density, \( N_H = 3.45 \times 10^{21} \) cm\(^{-2}\), was adopted from the current XMM-Newton measurements (Willingale et al., 2001). Spectral modelling was done using XSPEC 11.3 (Arnaud, 1996).

Fig. 1 shows the ratios between the INTEGRAL Crab data and the canonical model. Spectra from revolution 102 (15-17 August 2003) were extracted with the OSA 3.0 software. For all instruments the absolute normalization is still not perfect. The result for JEM-X 2 is not satisfying below 7 keV. This is due to an incorrect flux reconstruction for lower energies and makes the spectra appear more absorbed than they actually are. The ISGRI case is the worst, with the spectrum being distorted by ‘snake-like’ features below 100 keV and with declining flux above 200 keV. The SPI spectrum, except for normalization, agrees well with the model, being quite smooth in the 30-200 keV range.

Fixing the canonical model parameters we have fitted the relative normalization parameters for the INTEGRAL instruments. (JEM-X 2 spectra are always fitted in the 7-21 keV range in the following, while the energy range used in fitting for ISGRI and SPI is that shown in figures.) The fit is bad and releasing the power law index does not improve it. For individual instruments we obtain almost acceptable fits for JEM-X 2 and SPI, but with a model which is a little too flat in the JEM-X 2 case. The ISGRI model gives a slope equal to the canonical value but the fit is poor. All these results are listed in Table 1. During fitting we have applied only statistical errors, except for ISGRI, for which we have tested an alternative fit, after adding systematical errors of 10% to the data. This leads to an acceptable \( ^2 \) and a quite good absolute normalization but with a larger slope.

It should be mentioned that the ISGRI spectra shown here were extracted for science windows with the source being
on axis. Selecting data with the object in the fully coded field of view gives a worse, lower normalization, about 50% of that obtained for on-axis spectra.

In Fig. 2 we present the comparison between the Crab spectra extracted with the OSA 3.0 and OSA 2.0 packages. The data for SPI are not shown, since for SPI there was no change in the software affecting the calibration in these two OSA releases. Both JEM-X 2 and ISGRI data from OSA 2.0 are farther from the proper absolute normalization. However, with OSA 3.0 the 'absorption' feature mentioned above arises for JEM-X 2. The scattering of the ISGRI flux is suppressed for OSA 3.0 in comparison to OSA 2.0 but the overall spectral shape remains bad. Please note the good agreement between the absolute JEM-X 2 and ISGRI fluxes at 20 keV with OSA 3.0.

![Figure 2. INTEGRAL Crab data from revolution 102 divided by the canonical model, comparison between spectral extraction done with OSA 2.0 and OSA 3.0.](image)

Table 1. Results of spectral fitting obtained for Crab spectra from INTEGRAL revolution 102. C values are the relative normalization factors, A and are parameters of the power law model. The second fit for ISGRI was done after adding systematic errors of 10% to the data. Fixed parameters are denoted with f.

| Instrument | $C_{\text{JEM-X 2}}$ | $C_{\text{ISGRI}}$ | $C_{\text{SPI}}$ | $A$ | $\chi^2$/NDF |
|------------|-------------------|-------------------|-----------------|-----------------|-----------------|
| INTEGRAL   | 0.82              | 0.75              | 1.21            | 9.7f            | 2.1f            | 9320/98         |
| INTEGRAL   | 0.80              | 0.73              | 1.18            | 9.7f            | 2.09            | 9302/97         |
| JEM-X 2    | 1.0               | -                 | -               | 6.95            | 2.05            | 41.8/19         |
| ISGRI      | -                 | 1.0               | -               | 7.22            | 2.10            | 9146/43         |
| ISGRI(10%) | -                 | 1.0               | -               | 10.4            | 2.19            | 48/43           |
| SPI        | -                 | -                 | 1.0             | 10.8            | 2.08            | 82.5/33         |

### 3. WEAKER SOURCES

Since INTEGRAL spectra are background dominated, the spectral extraction for weak sources becomes more dependent on the background model. Therefore, cross-calibration tests made for a strong source, such as the Crab, obviously will not exhaust all the issues of the INTEGRAL calibration. Below we present a review of a simple study of the INTEGRAL spectral shapes obtained for sources with relatively medium (Cyg X-1) or weak (3C 273, NGC 4151) fluxes.

As these sources exhibit some spectral variability, there is no canonical model for them and the tests are more difficult than in the Crab case. For comparison’s sake we adopted as a reference the data collected by RXTE simultaneously with the INTEGRAL observations. We used the XSPEC models $\text{constant*phabs (diskbb+comptt+reflect (comptt)+gauss)}$ for Cyg X-1, $\text{constant*wabs *powerlaw}$ for 3C 273 and $\text{constant*wabs*absnd*(cutoffpl+zgauss)}$ for NGC 4151 ($\text{absnd}$ is a local model for partial covering absorption). The relative normalization was fixed at 1.0 for HEXTE, we adopted $N_H$ values from the HEASARC nH column density tool, and we used solar abundances. Figs. 3-5 present the ratios between the INTEGRAL data and the best fit RXTE model for Cyg X-1, NGC 4151, and 3C 273, respectively.

#### 3.1. Cyg X-1

Cyg X-1 was observed by INTEGRAL during revolution 11 (16-18 November 2002) and by RXTE on 16 November 2002. The ratios between the INTEGRAL data and the RXTE model obtained for this object are similar to those shown in Figure 1 for the Crab. This is not surprising since the Cyg X-1 2-20 keV flux is equal to 1.1 photons cm$^{-2}$ s$^{-1}$, i.e., comparable with the Crab flux of 2.8 photons cm$^{-2}$ s$^{-1}$. Nevertheless, the SPI flux in the 150-300 keV range is lower than the corresponding values for Crab. For ISGRI the data/model ratio resembles that of the Crab, with deformations below 100 keV and with declining flux for higher energies.

![Figure 3. INTEGRAL data for Cyg X-1 from revolution 11 compared to the RXTE best fit model. A JEM-X 2 spectrum was not extracted due to its non-standard operation mode for this revolution.](image)
3.2. NGC 4151

INTEGRAL observation of NGC 4151 was performed during revolutions 74-76 (23-29 May 2003). Corresponding RXTE campaign was shorter: useful data for PCA are from the period 24-29 May 2003 and for HEXTE only from 27-29 May 2003. The 2-20 keV flux fitted to the PCA data of NGC 4151 is equal to 0.045 photons cm$^{-2}$ s$^{-1}$. For an object about 100 times fainter than the Crab the overall shapes of the JEM-X 2 and ISGRI data-to-model ratios are still similar to the Crab results, however, with a different normalization, very close to 1. This apparent agreement of the INTEGRAL instruments absolute flux with the HEXTE results can be explained by the fact that HEXTE data were collected during two short periods of INTEGRAL observation, when the source flux was, on average, about 20% lower than the flux measured during all 7 days.

Figure 4. INTEGRAL data for NGC 4151 from revolutions 74-76 compared to the best fit RXTE model. Due to the staring observation strategy a spectrum for SPI was not extracted.

3.3. 3C 273

3C 273 was observed simultaneously by INTEGRAL (revolution 82) and RXTE on 16 June 2003. This is the weakest source in our sample, with a 2-20 keV flux equal to 0.027 photons cm$^{-2}$ s$^{-1}$, and due to this fact its results are less conclusive. The relative normalizations obtained for the INTEGRAL instruments are clearly lower than the corresponding values derived for stronger sources. This can possibly be explained by the background model being worse. Again, the JEM-X 2 and ISGRI spectra descend too much on their lower and higher energy boundaries, respectively. The decrease of the ISGRI flux with increasing energy can be explained by the inefficiency of the standard extracting method, working on individual science windows. As can be seen from Figs. 1, 3-5, this effect correlates with the decreasing source strength. The alternative ISGRI spectrum (O) extracted in a non-standard way, from the mosaic image, looks better than the standard (S), being almost undeformed below 100 keV and without steepening above 100 keV. However, its absolute normalization is somewhat worse than in the ISGRI (S) case. The SPI data are uncertain and probably exhibit some background contamination because of the presence of strong instrumental lines in this range.

For the details of the spectral modelling for these three sources we refer the reader to the posters devoted to them. For this review we have only fitted the relative normalization for INTEGRAL instruments, with the rest of model parameters fixed at the RXTE values. The results are gathered in Table 2. As stated before, the absolute normalization for weaker objects is still uncertain. (We do not quote $^5$ values for these results since they are not relevant for such a limited fit.)

Figure 5. INTEGRAL data for 3C 273 from revolution 82 compared to the RXTE best fit model. For ISGRI an alternative approach to the spectral extraction is presented, where the overall observation spectrum (O) is prepared from the mosaic image, instead of summing the spectra obtained for individual science windows (S).

Table 2. Relative normalization factors fitted for INTEGRAL spectra of Cyg X-1, 3C 273 and NGC 4151, with the other parameters fixed at the best fit values obtained for RXTE data. For ISGRI (S) we show also the value obtained for spectrum below 100 keV.

| Object  | $C_{\text{JEM-X 2}}$ | $C_{\text{ISGRI (S)}}$ | $C_{\text{ISGRI (O)}}$ | $C_{\text{SPI}}$ |
|---------|----------------------|------------------------|------------------------|------------------|
| Cyg X-1 | -                    | 0.74                   | -                      | 1.32             |
| 3C 273  | 0.72                 | 0.52/0.56              | 0.37                   | 0.82             |
| NGC 4151| 1.01                 | 1.11                   | -                      | -                |

4. CONCLUSIONS

INTEGRAL spectra extracted currently should be treated with caution. At the present time none of the INTEGRAL instruments can be used to measure the absolute flux. The major problem of JEM-X 2 with respect to the spectral shape is the artificial absorption excess observed below 7 keV. The response matrices for ISGRI are still prelimi-
nary and the spectra are too deformed to be used for detailed spectral modeling. Only SPI does not exhibit any serious problems in its spectral shape calibration. The calibration of the INTEGRAL instruments is in progress, the new major release 4.0 of OSA should solve many of the issues discussed here.

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