INTEGRAL Cross-calibration Status between 3 keV and 1 MeV

Answer to IUG action 05-4 by Instrument teams

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I-Introduction:

This report presents the status of INTEGRAL instrument calibration after the OSA-7 release. We first summarize the status of each instrument, then a common fit will give the inter-calibration picture.

II-Instrument calibrations:

- JEM-X

The results reported here are based on the OSA7 release with standard spectral extraction. Work is in progress to include the modelling of the gain effects into the next release of OSA. There are several conditions that have made the determination of the instrument response uncertain:

1. The instrument is operated at a much lower gain[1] than anticipated when designing the electronic system which implies that at low energy the electronic event acceptance threshold cuts in.
2. The gain is slowly increasing with time, a process that is counteracted by lowering the high voltage in steps from time to time.
3. The anodes have varying properties – some are more active than others in a time dependent way.
4. The event rejection to avoid the particle background has some properties that again are difficult to model.
5. The spectral extraction procedure may be dependent on energy since e.g. the penetration of photons into the gas is energy dependent as is the event localization accuracy.

Due to this the JEM-X team has chosen to calculate the ancillary response function (ARF) from on-axis Crab observation by assuming a canonical spectrum of photon index 2.1 and normalization 9.7 ph/cm2/s/keV at 1.0 keV. By an inverse process the ARF is derived while requiring a degree of smoothness. However, above 12 keV the effects of the gain and electronic threshold have disappeared and there we use the shape of the ARF as deduced from the absorption properties of the Xe gas coupled with the treatment of escape events, but the normalization is adjusted to the expectation.

It must be emphasized that the shape of the Crab spectrum above 12 keV is fully compatible with the photon index of 2.1.

[1] To avoid the anode destruction

Orbit 300 data: 15 ks of useful duration (ARF derived from earlier observations):

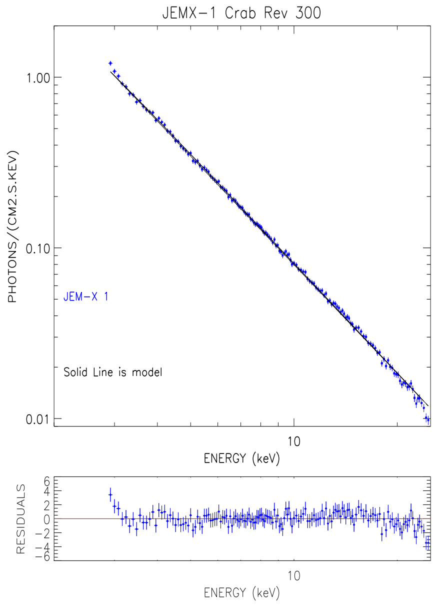
<u>JMX1</u>

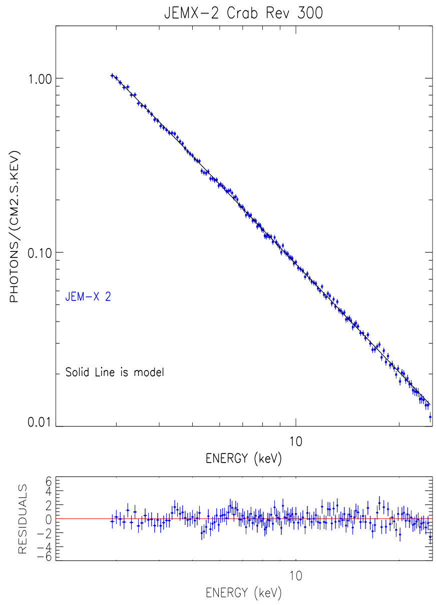
Photon Index = 2.15±0.05 Flux @ 1 keV = 11.3±0.1 photons cm^{-2} s^{-1} keV^{-1}, NH = 0.35×10^{22} cm^{-2} (frozen)

<u>JMX2</u>

Photon Index = 2.07±0.05 Flux @ 1 keV = 10.2±0.1 photons cm^{-2} s^{-1} keV^{-1}, NH = 0.35×10^{22} cm^{-2} (frozen)

For both instruments the energy flux from 2 – 10 keV is 2.28×10^{-8} erg cm^{-2} s^{-1}





- <u>ISGRI</u>

The determination of the energy deposit of each photon in the ISGRI CdTe detectors is not an easy task, since the energy is a function of two parameters, rise time (RT), and amplitude (PHA). The difficulty lies in the fact that these two parameters may be degenerate. This means that for a given energy more than one (RT, PHA) couple is possible. This requires a careful statistical treatment of the events that is now implemented in OSA 7, thanks to the LUT2_3D. In addition, due to the space environment the ISGRI response drifts with time. This drift is now mainly corrected through the combined information of different particle counters on board the satellite derived from the IREM instrument. Despite the recent improvements there is a residual minor drift and overall systematics in the spectra that are still not acceptable. That is why the ISGRI response matrices (in particular the ancillary response function, ARF) derived by means of Montecarlo simulations, and based on the current knowledge of the instruments, are corrected "a posteriori" in order to match the SPI Crab spectrum, which is taken as an independent absolute measure. These corrected response matrices, included in the OSA7 distribution, yield an acceptable Chi squared for all Crab observations (syst. 1%) performed throughout the mission and stable spectral parameters, and can hence be used by the users for their analysis under all circumstances, see Section III.
For what concerns, on the other hand, the absolute measure of the Crab spectrum by the ISGRI instrument using only the Montecarlo derived ARF (i.e. before the correction done in order to meet the SPI spectrum) the following can be stated:

- the spectra clearly indicate the necessity of a break around 100 keV, but the response above this energy is not completely stable, and hence the slope above the break cannot be firmly measured
- fitting ISGRI spectra below 100 keV with power laws and these matrices results in a photon index of about 2.13, which is very close to the SPI value. The spectra slopes for the different revolutions are compatible within errors, but the level of systematics is still high. The derived spectral parameters below 100 keV are:

Orbit 300 data: 31 ks of useful duration

Photon Index = 2.12±0.03   Flux @ 100 keV = 6.5×10^{-4} photons cm^{-2} s^{-1} kev^{-1}

Orbit 605 data: : 60 ks of useful duration

Photon Index = 2.13±0.03   Flux @ 100 keV = 6.2×10^{-4} photons cm^{-2} s^{-1} kev^{-1}

These values are very similar and compatible at ~ 2 σ level with the ones derived by SPI. This proves that below 100 keV ISGRI can give an independent and stable estimate of the Crab spectrum, while some more work is needed to assess the response at high energies and to get rid of the residual systematics (visible with narrow bands) below 100 keV.

- <u>SPI</u>

Previous studies on the Crab observations have demonstrated that the SPI telescope performances are stable from the beginning of the mission at least up to 300 keV.
The source itself being stable, to add several observations is a reasonable way to get a more significant signal to noise ratio up to 1 MeV.

For SPI, we thus have added all revolutions available in the same configuration (with 17 detectors available, ie after revolution 214)). The data set has been restricted to “5x5” patterns in order to be representative of nominal SPI operations.
This leads to **325 ks of useful duration**, distributed over 7 revolutions.
The data below 22.5 keV are to be excluded since the matrix is less precise in this domain. Moreover, the effect of the low energy threshold is not properly taken into account. Some work is needed on this point.

Fit with a broken power law model:
When going toward higher energies (~ above 100 keV), we can see that the global shape presents a slight curvature that can be approximated by a break in the (low energy) power law, suggesting a broken power law model. However, in this framework, we are facing a strong degeneracy in the parameter determination that we have chosen to solve by fixing the energy of the break at 100 keV.

<u>Fit of SPI spectrum alone (from 23. keV to 1 MeV), 0% systematic: Results</u>

Model :
a broken power law
with E_{break} fixed to 100 keV

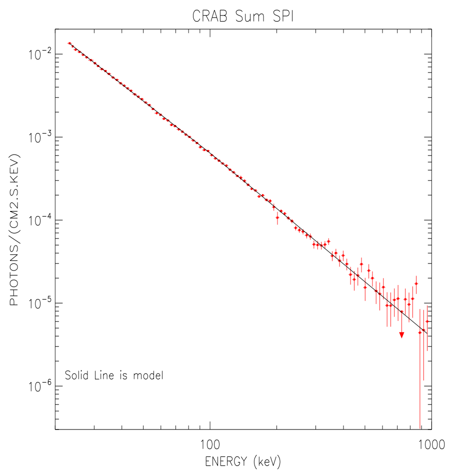
Photon Index 1 : 2.08 +/- 0.01

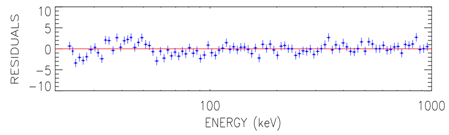
Break Energy : 100.000 keV frozen

Photon Index 2 : 2.22 +/- 0.03

Flux @ 100 keV: 6.4 [± 4 10^{-2} (stat) ± 1.2 10^{-1} (sys)] x 10^{-4} photons cm^{-2} s^{-1} kev^{-1}

Extrapolated flux@1 keV :
9.28 ± 0.2 photons cm^{-2} s^{-1} kev^{-1}





III- The Integral Crab:

We then fit simultaneously JEM-X, ISGRI and SPI data with an absorbed broken power law with E_{break} fixed to 100 keV and N_h fixed to 0.35 10^{22} cm^{-2}.
JEM-X 1 and 2 data have been used from 3 to 25 keV (15 ks in revolution 300).
ISGRI data have been used from 14 keV to 1 MeV (31 ks in revolution 300), as in Section II but with OSA-7 ("corrected") matrix.
SPI data have been used from 23 keV to 1 MeV as in Section II (325 ks from rev 239 to 605).

Systematics have been added at a level of 3% for JEM X-1 & 2 and 1% for ISGRI and SPI.

Results:

Model : a broken power law
with Ebreak fixed to 100 keV
plus an absorption
with Nh fixed to 0.35 10^{22} cm^{-2}

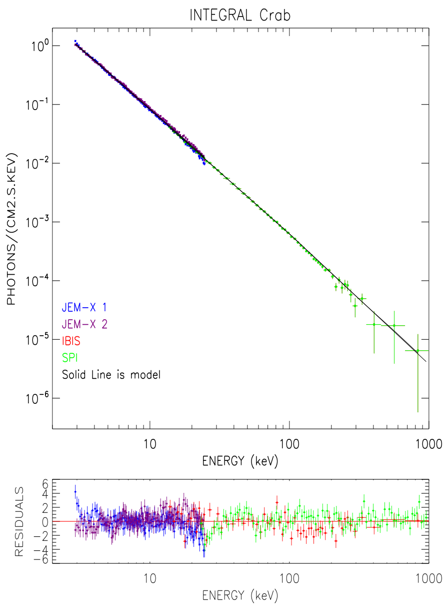
Photon Index 1 : 2.105 +/- 0.3 10^{-2}

Break Energy : 100.000 keV frozen

Photon Index 2 : 2.22 +/- 0.2 10^{-1}

Flux @ 100 keV: 6.3 [± 1.5 10^{-2} (stat) ± 1.2 10^{-1} (sys)] x 10^{-4} photons cm^{-2} s^{-1} kev^{-1}

factor SPI fixed to 1.0
factor ISGRI : 0.99 +/- 0.2 10^{-2}
factor JEM X-1 : 1.022 +/- 0.3 10^{-2}
factor JEM X-2 : 1.06 +/- 0.3 10^{-2}



Notes:
Residuals are in sigma units in all figures.
Statistical errors on best-fit parameters have been calculated with Xspec but are just indicative as complete ones depend on systematic level, binning, etc.

IV- Conclusion

The presented work establishes that the INTEGRAL instruments give consistent results on the total Crab spectrum, with a global shape in agreement with observations from previous experiments. We have shown that for the ARFs provided with OSA 7, the cross-normalisation factors between the instruments are consistent with 1.0 within reasonably small errors, and the slope of the combined spectrum is consistent with those for the single instruments in the overlapping energy windows.