PROCEEDINGS OF SCIENCE

Hard X-ray properties of the INTEGRAL complete sample of AGN

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We consider the complete sample of AGN detected by INTEGRAL/IBIS in the 20–40 keV band and extracted from the the 3^{rd} IBIS survey [9]. The sample includes all sources detected above 5.2σ, can be used to provide an insight into the population of hard X-ray selected AGN. For the entire sample, we study the hard X-ray (20–100 keV) spectral properties, comparing them with SWIFT/BAT 58 months data: we give information on spectral and flux variability, average spectral shape and BAT/IBIS cross-calibration constant. We also provide an example of how the hard X-ray spectra can be used to constrain some important spectral parameters, such as reflection and/or high energy cut-off.

The Extreme sky: The Extreme and Variable High Energy Sky - extremesky2011,
September 19-23, 2011
Chia Laguna (Cagliari) Italy

 http://pos.sissa.it/

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1. Introduction

Observations of active galactic nuclei above 10 keV are essential for studying non-thermal processes and observing sources which are strongly affected by absorption in the soft X-ray band. Besides, studying AGN in the hard X-rays gives information on the high energy cut-off and the reflection fraction which cannot be explored with observations at lower energies alone. The determination of these parameters is important as they provide insight into the physical properties of the region around the central power source, play a key role in synthesis models of the cosmic X-ray background and are important ingredients for Unification theories and torus studies. Although broad-band measurements of AGN have been made in the past, mainly with the BeppoSAX satellite (e.g. [11]; [6]), these did not generally pertain to a complete sample of sources and were limited to a few bright near-by objects. This is now changing with the launch of instruments having both imaging and spectroscopy capabilities that can shed new light on the hard X-ray properties of AGN. In particular the imager *IBIS* (Imager on Board the INTEGRAL Satellite; [12]) on board the *INTEGRAL* (International Gamma-Ray Laboratory; [13]) satellite and the *BAT* (Burst Alert Telescope) instrument [1] on board *Swift* [7] have been surveying the high energy sky providing a wealth of detections of new and known active galaxies, which can be now studied in a systematic way for the first time over the 15–200 keV band. Here we present the hard X-ray properties of a complete sample of 87 AGN detected by *INTEGRAL* [9]. We make use of both *IBIS* and *BAT* spectra, with the aim of cross-calibrating the two instruments, studying source variability and constraining some important spectral parameters.

2. The Sample

The *INTEGRAL* Complete Sample of AGN has been extracted from a set of 140 extragalactic sources listed in the third *IBIS* survey [4]. All 140 sources have been firmly identified as AGN (63 of type 1, 64 of type 2 and 13 Blazars). The complete sample consists of 87 active galactic nuclei: 41 type 1 AGN (Seyfert 1, 1.2 and 1.5), 33 type 2 AGN (Seyfert 1.9 and 2), 5 narrow line Seyfert 1s (NLSy1s) and 8 Blazars (QSOs, BL Lacs and Blazars). The complete sample has been extracted by means of the V/V_{max} test. Briefly, this test consists of comparing the volumes contained within the distances where the sources are observed (V) with the maximum volumes (V_{max}), defined as those within the distance at which each source would be at the limit of detection. If the sample is not complete, the expected value for $<V/V_{max}>$ is less than 0.5, while when complete it should be equal to 0.5. Full details on the extraction of the complete sample are given in [9] and [10].

The *INTEGRAL* data used in our analysis consist of several pointings performed by *ISGRI* [8] in the period comprised between launch and the end of April 2008, for a total of almost 40000 science windows, i.e. *INTEGRAL* pointings. Full details on data reduction and product generation can be found in [4] and [5]. Analysis is performed in the 20–110 keV band, and spectra are fitted with XSPEC version 12.5.1, using a χ^2 statistics; errors are quoted at 90% confidence level for one parameter of interest ($\Delta\chi^2$=2.71). We also make use of publicly available *Swift*/BAT spectra, retrieved on the web[1]; these spectra are from the first 58 months of operations of the *Swift*/BAT

[1] http://swift.gsfc.nasa.gov/docs/swift/results/bs58mon/

telescope [2]. Note that the exposure times of the IBIS and BAT spectra are similar for the majority of our sources, although they do not necessary cover the same time periods.

3. BAT/IBIS spectral analysis: individual fits.

Figure 1 (left panel) shows the *IBIS* photon indices plotted against the *BAT* ones. There is overall good agreement between the *IBIS* and *BAT* photon indices, suggesting that our sources are not affected, on average, by changes in their spectral shapes. Only a few sources seem to deviate from the 1 to 1 line, suggesting a possible change in their spectral shape between the observations performed by the two instruments. However, the errors on both sides are large, thus indicating that a more appropriate analysis is needed. Only 3C 273 deviates significantly from the 1 to 1 line, suggesting a possible change in the photon index.

Figure 1 (right panel) shows the 20–100 keV *IBIS* flux versus the 20–100 keV *BAT* flux, both obtained from the individual fits to the high energy spectra. It is quite evident from the plot that there are significant deviations from the 1 to 1 line, suggesting that above 20 keV long term variability is likely in all types of objects. Also evident from the figure is the tendency for *BAT* fluxes to be more above the 1 to 1 line than below it, especially for dimmer sources: this can be interpreted as a sign of some systematics between the two instruments.

To quantify this mismatch we have calculated the ratios F_{IBIS}/F_{BAT} for the entire sample and fit a gaussian to their distribution in oder to estimate the mean and the relative error (the mean is 1.143 with an error of 0.035). We have then multiplied the *BAT* flux by this mean, taking into account the errors and then we calculated again F_{IBIS}/F_{BAT} to ensure that the new distribution is compatible within errors with a gaussian having mean 1 (the new value of the mean is 1.003 with an error of 0.028). We then estimated F_{IBIS}-$F_{BAT}/\sqrt{(\sigma^2_{IBIS}+\sigma^2_{BAT})}$, made the histogram of the values obtained and fitted a gaussian to it; at this point we evaluated how many sources deviate from this gaussian significantly and are therefore likely to be variable. We therefore consider a source variable if its 20–100 keV flux has changed by more than 3σ between the *IBIS* and *BAT* observations. 11 sources out of 80 ($\sim$14% of the sample) have undergone a change in their flux. In particular 4 of these variable sources are type 1 AGN, 2 are Blazars and 5 are type 2 objects.

AGN flux variability at hard X-rays has been discussed by [3], using *Swift/BAT* data for 44 bright AGN: they found that blazars show stronger variability than Seyfert 1 and Seyfert 2 galaxies, which instead present 10% flux variations or more in at least one third of the sources analysed. The comparison of our results with those of [3] is difficult, due to the different methods of analysis employed; we do not see more variability in blazars than in Seyferts, but the fraction of variable sources in their sample and ours is similar. While we would have expected flux changes to be smeared out when considering average fluxes over long timescales, the presence of 11 variable sources suggests that flux variability is common at hard X-ray energies, although its amplitude is not dramatic and contained within a factor of 2.

4. BAT/ISGRI spectral analysis: combined fits.

After the individual fits on *IBIS* and *BAT* spectra, we combined the two datasets and fit them together. To take into account those few cases affected by flux variability and the likely mismatch

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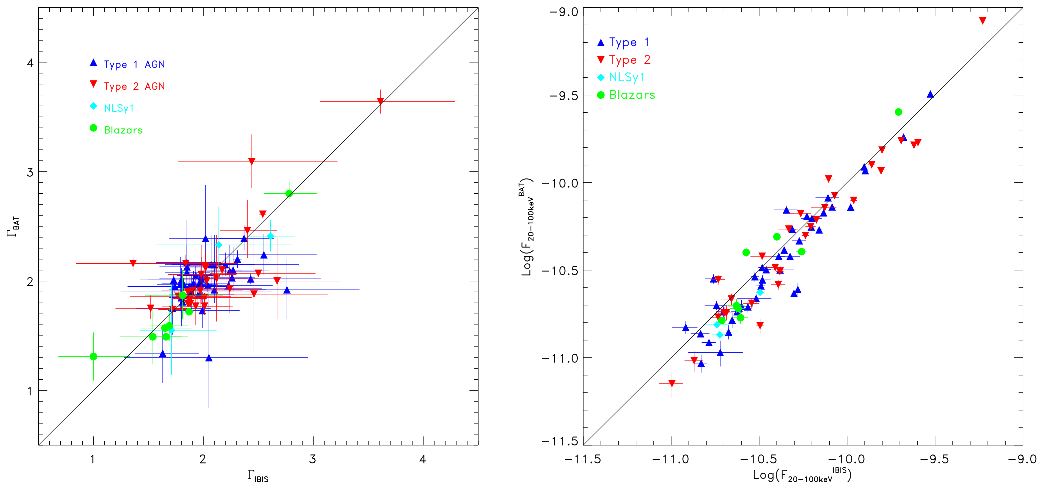

Figure 1: *Left Panel: IBIS* vs *BAT* photon indices derived from individual fits, employing simple power-law model (absorbed by intrinsic column density in case of type 2 AGN). *Right Panel:* 20–100 keV fluxes derived from individual fits of *IBIS* and *BAT* spectra.

between the *IBIS* and *BAT* spectra, we have introduced a cross-calibration constant, C in the fit. The model employed is a simple power-law, absorbed by intrinsic column density in the case of Type 2 sources, where very high absorption could still affect the spectral shape even above 20 keV.

In the left panel of figure 2 the distribution of the cross-calibration constants is shown. As can be seen from the plot, most sources have cross-calibration constants around 1–1.5, implying that in most cases the IBIS flux is higher than the BAT one; the mean value of C is 1.14$\pm$0.04, with a dispersion of 0.24. Note that this value is close to the one that would be obtained if the Crab nebula was fitted simultaneously by the two instruments. The distribution, however, shows a tail towards higher values of C, again an indication of the presence of variable sources in our sample.

Figure 2 (right panel) shows the photon indices (Γ) distributions for the entire sample and for each class of objects. For the entire sample, the average photon index is 2.00, with a standard deviation of 0.33; for type 1 AGN we find $<\Gamma>$=1.98 (σ=0.17) while for type 2 AGN we find $<\Gamma>$=2.10 (σ=0.41). Blazars have instead a slightly flatter average photon index, i.e. $<\Gamma>$=1.74 (σ=0.46). We therefore do not find any dramatic difference between the average photon indices of type 1 and type 2 AGN, suggesting that the mechanism that produces the high energy emission is the same. It is also worth noting that the simple power-law model employed generally gives acceptable fits, although there are some sources that are not well described by such model. This is indeed an indication of the presence of some degree of spectral complexity, requiring additional components to better describe the high energy emission of these sources. In particular, we find that a simple power-law is not sufficient to describe the high energy spectrum of 22 of our sources (25% of the sample). However, when a high energy cut-off and/or a reflection component are added, the fits yield better results. An example is GRS 1734-292, whose spectrum is well described by a power-law with a well constrained high energy cut-off (see figure 3). Nonetheless, it is difficult to get good constraints on all 3 parameters (photon index, cut-off energy and reflection) at the same time, therefore highlighting the need for broad-band spectra for such task.

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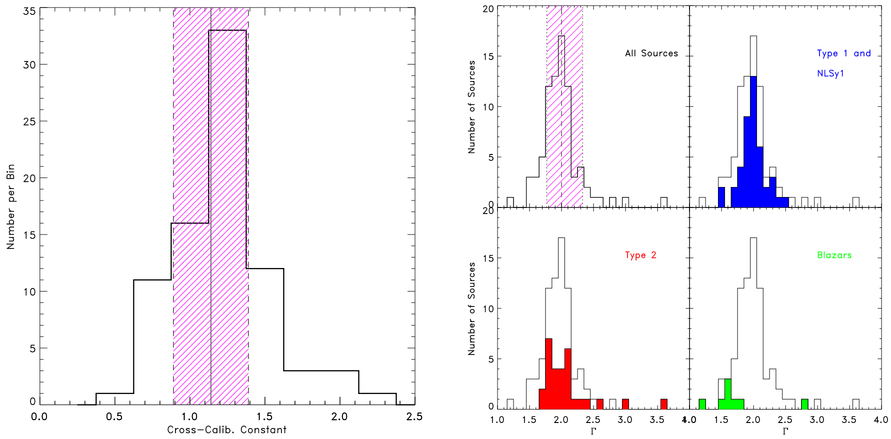

Figure 2: *Left Panel: IBIS* vs *BAT* cross-calibration constants distribution. The vertical solid line represents the average value of *C*, the dashed lines and the hatched area represent the parameter dispersion. *Right Panel:* photon indices distributions, divided by source class. Values are obtained from combined *IBIS*/*BAT* spectral fits.

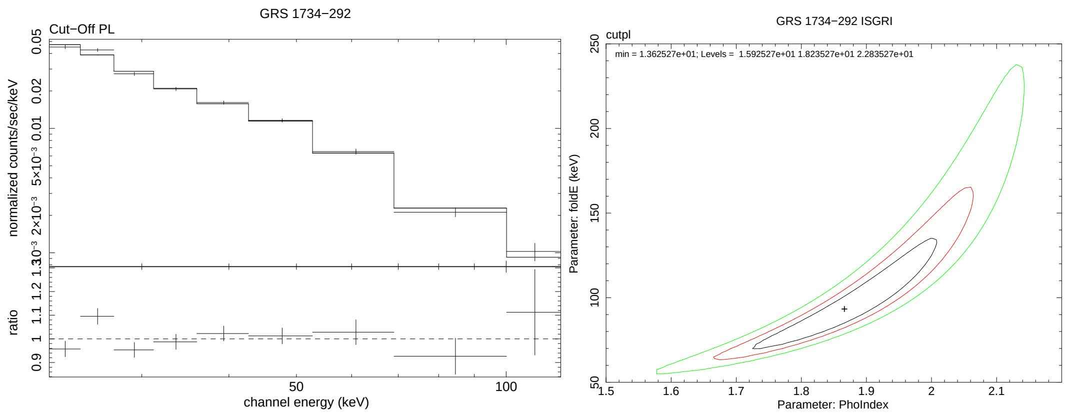

Figure 3: *Left Panel:* IBIS spectrum of the Seyfert 1 GRS 1734-292, the model employed is a cut-off power law. As can be seen from the data-to-model ratio, the model well describes the spectral shape of the source. *Right Panel:* confidence contour levels of the photon index versus the high energy cut-off for GRS 1734-292.

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