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The average hard X-ray Spectrum of Narrow-Line Seyfert Galaxies

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We present a deep study ($\sim$ 10 Ms) of the average hard X-ray (17–250 keV) spectrum of the 14 narrow-line Seyfert 1 galaxies detected by *INTEGRAL* IBIS/ISGRI. Similarly to what observed at lower energies, the hard X-ray spectrum of narrow-line Seyfert 1s is steeper than that of their broad line counterparts. This is likely related to a lower energy of the cutoff. The hard X-ray luminosity and column density distributions also differ between the two samples, with narrow-line Seyfert 1s being less luminous and less absorbed than broad-line Seyfert 1s.

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1. Introduction

Narrow Line Seyfert 1s (NLS1s) are a peculiar type of Seyfert galaxies, characterized in the optical by permitted lines only slightly broader than the forbidden ones. It has been suggested that NLS1 are AGN in their early phase ([10]), characterized by relatively small black hole masses (e.g., [11]) and very high accretion rates in terms of Eddington units (e.g., [13]). In this scheme the small black hole mass would be responsible for the narrow optical lines, the matter in the broad line region (BLR) having lower velocities than in broad line Seyfert 1s (BLS1s).

Some of the most remarkable properties of NLS1s are seen in the soft X-rays (0.1–10 keV). At these energies NLS1s show a very strong X-ray variability on short timescales (e.g., [6]), and a continuum normally steeper than that of their broad lines counterparts (e.g., [18]). Both these characteristics can be explained by black holes with small masses. NLS1s normally show also a very strong soft excess above the power-law continuum below 2 keV. Broad-band X-ray observations have recently shown that some NLS1s present a hard excess over the power-law continuum (e.g., [22]). The nature of this feature is still discussed, and it might be due either to the presence of partially covering material (see [23] for a review) or to the enhancement of the reflection component caused by light bending (e.g., [17]).

Due to their steep X-ray continuum, few NLS1s are detected above 20 keV, and so far only a handful of them have been studied at hard X-rays. Of the ~ 200 Seyfert galaxies detected by *INTEGRAL* IBIS/ISGRI in the 17–80 keV band ([4], [19]), 14 are NLS1s, representing $\simeq 15\%$ of the total number of Sy1s and Sy1.5s. This is a much smaller fraction compared to the $\sim 50\%$ of *ROSAT* soft X-ray selected NLS1s [12], but it is consistent with the $\sim 15\%$ obtained from optically selected samples (e.g., [25]). Here we present a deep study of the hard X-ray characteristics of the 14 NLS1s detected by *INTEGRAL* IBIS/ISGRI.

2. Sample and data analysis

The *INTErnational Gamma-Ray Astrophysics Laboratory* (*INTEGRAL*; [26]) is a hard X-ray/soft γ-ray mission, launched in October 2002, and designed for imaging and spectroscopy with high angular and spectral resolution. The soft gamma-ray imager IBIS/ISGRI (15–1000 keV; [15]) on board of *INTEGRAL* has detected for the first time in the hard X-rays (20–100 keV) several hundred sources ([5]).

In Table 1, we list the 14 sources of our sample, the values of the column density $N_{\rm H}$ are inferred from soft X-rays observations ([19] and references therein). The luminosity distribution of NLS1s and that of BLS1s are shown in Fig. 1. The two distributions are significantly different, with NLS1 being less luminous than BLS1s, as observed at other wavelengths. A Kolmogorov-Smirnov (KS) test results in a probability of $\simeq 10\%$ that the two samples are drawn from the same population. The mean value of the 17–80 keV luminosity is of $L_{\rm BLS1} = 4.7 \times 10^{43}\,{\rm erg\,s^{-1}}$ for BLS1s, and of $L_{\rm NLS1} = 1.7 \times 10^{43}\,{\rm erg\,s^{-1}}$ for NLS1s. The hydrogen column density distribution of NLS1s is also significantly different from those of BLS1s and Sy1.5s (Fig. 2). A KS test gives a probability of $\sim 10\%$ that the $N_{\rm H}$ distributions of NLS1s and of BLS1s are drawn from the same parent population. The average value of $N_{\rm H}$ is lower for NLS1s ($1.9 \times 10^{21}\,{\rm cm^{-2}}$) than for BLS1 ($1.8 \times 10^{22}\,{\rm cm^{-2}}$).

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Table 1: Detection significances (1), exposures (2), column densities (3) and luminosities (4) of our sample of *INTEGRAL* IBIS/ISGRI detected Narrow Lines Seyfert 1s. Detection significances and luminosities are in the 17–80 keV band.

Name	(1) Det. significance $[\sigma]$	(2) Exposure [ks]	(3) $N_{\rm H}$ $[10^{22}\,{\rm cm}^{-2}]$	(4) $\log L_{17-80\,{\rm keV}}$ $[{\rm erg\,s}^{-1}]$
1H 0323+342	5.9	635	0.1	43.97
Mrk 110	5.0	28	0.019	44.09
NGC 4051	13.6	742	< 0.02	41.34
Mrk 766	7.7	790	0.8	42.71
NGC 4748	5.2	528	$\simeq 0$	42.57
Mrk 783	7.3	788	0.046	44.12
NGC 5506	47.2	358	3.4	43.19
IGR J14552−5133	12.5	1404	0.1	42.88
IRAS 15091−2107	5.3	285	0.7	43.70
IGR J16185−5928	10.7	1261	< 0.1	43.52
IGR J16385−2057	7.7	851	0.21	43.35
IGR J19378−0617	11.2	858	$\simeq 0$	42.58
ESO 399−20	6.5	517	0.048	43.23
IGR J21277+5656	24.2	1090	0.1	43.08

Notes. Hydrogen column densities from [19] and references therein.

We produced the average hard X-ray spectrum of our sample of hard X-ray selected NLS1s following the procedure adopted by [24]. We created 500×500-pixels mosaic images modifying the coordinate system of each individual image, setting the coordinates of each source of the sample to an arbitrary fixed position (α=0, δ=0). The geometry of each image was modified in order to have consistent PSF whatever the position of the source in the field of view (FOV). The mosaic image provides a stack of all the IBIS/ISGRI data of each source. In figure 3 we show the central part of the 17-80 keV mosaic image. The total exposure of the mosaic is ~ 10 Ms, and the average emission of NLS1s was detected with a significance of 44.3σ and a flux of $0.377 \pm 0.008\,{\rm ct\,s}^{-1}$. Individual sky images for each pointing were divided in 10 bins. The spectra were extracted from the mosaics using the task `mosaic_spec`.

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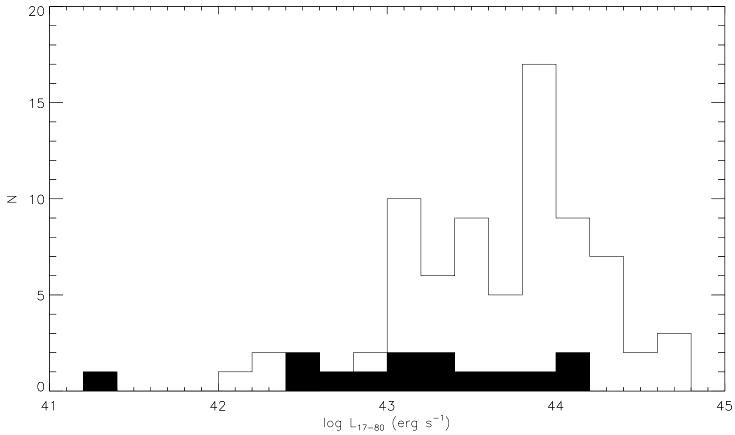

Figure 1: Luminosity distributions of the BLS1s (*empty histogram*) and NLS1s (*filled histogram*) of our hard X-ray selected sample.

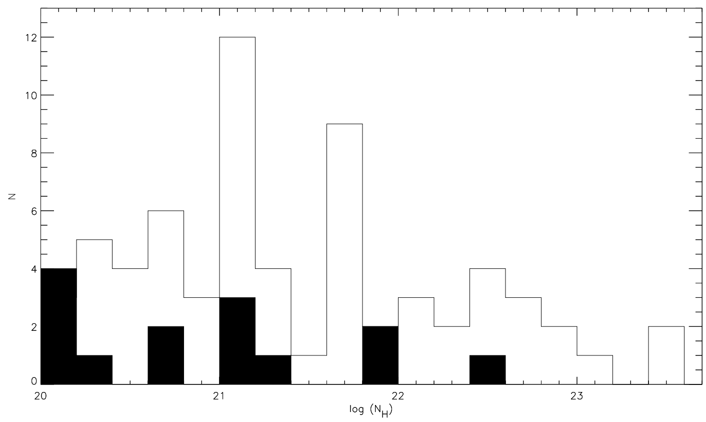

Figure 2: Hydrogen column density distributions of the BLS1 (*empty histogram*) and NLS1s (*filled histogram*) of our hard X-ray selected sample.

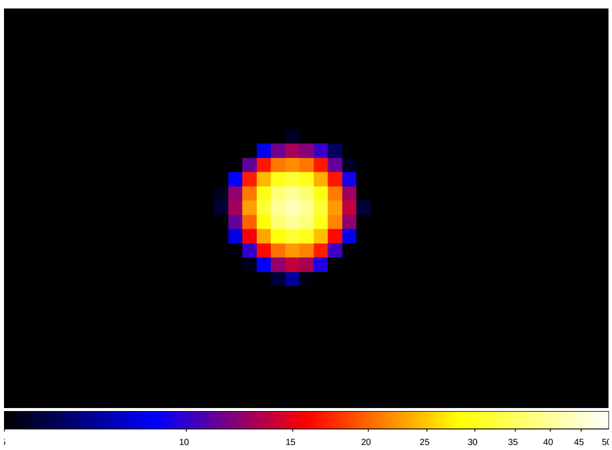

Figure 3: Composite image of the central part of the 17–80 keV *INTEGRAL* IBIS/ISGRI mosaic.

Table 2: Results obtained from the spectral analysis of the average hard X-ray spectra of NLS1s. The inclination angle *i* was fixed to 45°.

Model	Γ	E_C [keV]	R	χ^2	DOF
Narrow Line Seyfert 1s					
Power law	$2.23^{+0.08}_{-0.08}$	–	–	24.6	8
Cut-off power law	$1.7^{+0.2}_{-0.6}$	70^{+43}_{-36}	–	11.6	7
*Pexrav	$2.28^{+0.08}_{-0.08}$	–	≥ 1.3	9.5	7
Pexrav	$2.3^{+0.1}_{-0.6}$	≥ 53	≥ 0.1	9.5	6

Notes. *Pexrav: the high-energy cut off was not included, being fixed to its upper limit $E_C = 10^6$ keV.

3. The average hard X-ray spectrum of NLS1s

A model-independent approach to the spectral analysis is often a good way to constrain differences and similarities between different spectra. In Fig. 4 we show the normalized average hard X-ray spectra of NLS1s and Sy1s (from [19]) and their ratio. The ratio diverges from the unity from $\sim$ 40 keV, with the spectrum of NLS1s being steeper than that of Sy1s. From a model-dependent spectral analysis (Table 2) we found that the average hard X-ray spectrum of NLS1s cannot be well represented by a simple power law model. Adding a cutoff or a reflection component improves significantly the fit. Using a cutoff power law plus reflection from neutral matter (*pexrav* in Xspec) we obtained a photon index of $\Gamma = 2.3^{+0.1}_{-0.6}$, a lower limit of the energy of the cutoff of $E_C \geq 53$ keV, and of the reflection parameter of $R \geq 0.1$.

Using *INTEGRAL* IBIS/ISGRI data (up to 100 keV), [16] found that the spectra of NLS1s present a continuum significantly steeper than Seyfert 1s, and interpreted this as being due to a low energy ($E_C \leq 60$ keV) of the cutoff. From our analysis, we confirmed that also in the hard X-rays the average spectrum of NLS1s is steeper than that of BLS1s, with the spectra clearly diverging above $\sim$ 40 keV. This might be due either to different values of Γ or to different energies of the cutoff. The fact that up to $\sim$ 40 keV the average spectrum of NLS1s is consistent with that of Sy1s favors the hypothesis that the photon indices are consistent, while the energy of the cutoff is lower for NLS1s. Another possible solution is that NLS1s have a stronger reflection component and a continuum steeper than BLS1s. However, soft X-ray observations of the sources of our sample ([1], [16], [14],[27], [21]) show that for all the objects for which good quality data are available the photon index is not significantly steeper than for BLS1s. Thus, the most likely explanation is that the energy of the cutoff is different for the two populations. This would imply a difference in the physical characteristics of the Comptonizing medium, and a lower temperature of the electrons in the coronas of NLS1s. Consistent photon indices might be due to a bias towards low values of Γ of our hard X-ray selected sample.

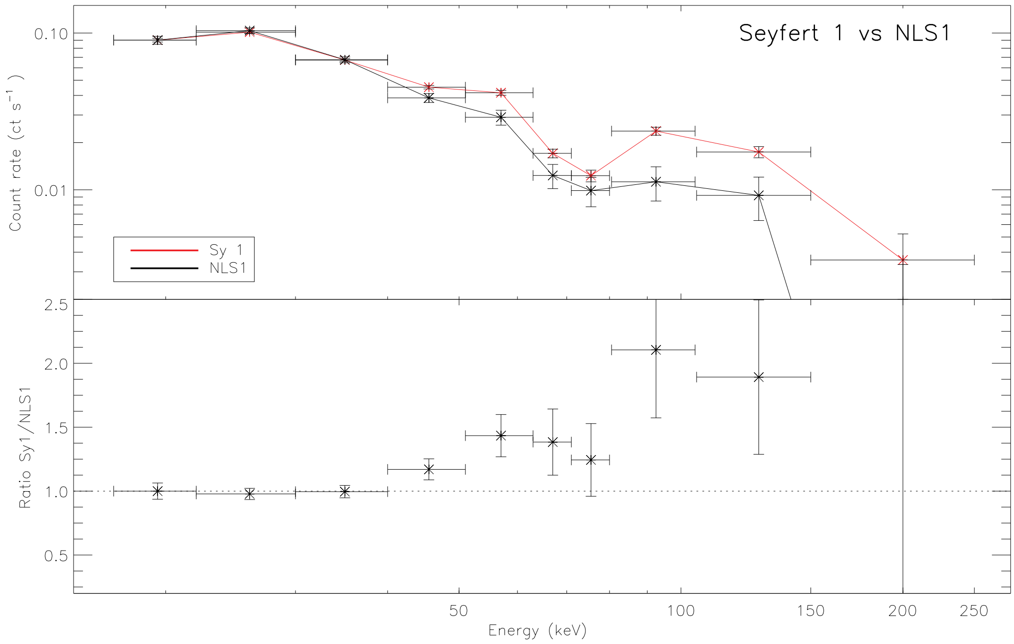

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Figure 4: Normalized average hard X-ray spectra of broad-line Seyfert 1s and NLS1s (*upper panel*) and their ratio (*lower panel*).

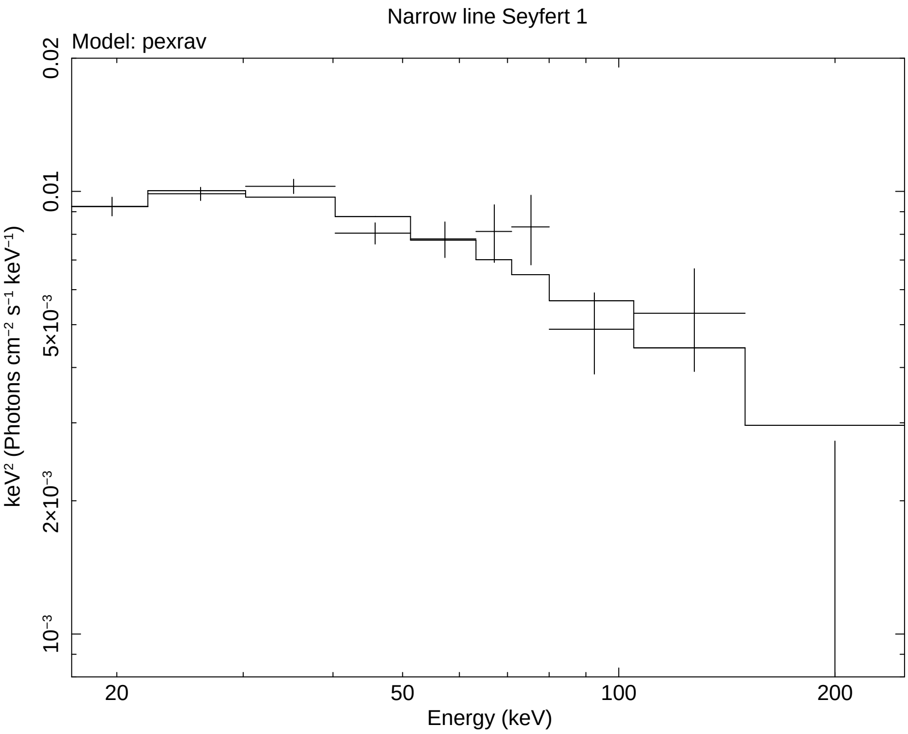

Figure 5: Average hard X-ray spectrum of NLS1s. The model used is a cutoff power law plus reflection from neutral matter.

Table 3: *Swift*/BAT detection significances in the 14–195 keV band (1), and values of $F_{\rm var}$ for 13 of the 14 sources of our sample (2). IGR J16385−2057 is not reported in the BAT 58-months catalog.

Name	(1) Det. significance [σ]	(2) $F_{\rm var}$
1H 0323+342	8.9	~ 0
Mrk 110	30.4	0.19 ± 0.06
NGC 4051	24.2	~ 0
Mrk 766	14.6	~ 0
NGC 4748	6.1	~ 0
Mrk 783	9.0	~ 0
NGC 5506	95.0	0.27 ± 0.02
IGR J14552−5133	8.8	~ 0
IRAS 15091−2107	7.2	~ 0
IGR J16185−5928	6.4	~ 0
IGR J19378−0617	8.9	~ 0
ESO 399−20	6.6	~ 0
IGR J21277+5656	19.5	0.1 ± 0.3

4. Hard X-ray variability

NLS1s are known to be very variable on short timescales in the soft X-rays. At hard X-rays only few NLS1s are known to be variable (e.g., 1H 0323+342 [8]). We studied the hard X-ray variability on a month time-scale of 13 sources of our sample (IGR J16385−2057 is not reported in the BAT 58-months catalog) using the Burst Alert Monitor (BAT) on board of *Swift* [2]. The monthly-binned *Swift*/BAT light-curves were taken from the 58-months catalog[1] [3]. To characterize the variability we used the fractional root mean squared (rms) variability amplitude $F_{\rm var}$ ([7]). In Table 3, we show the values obtained. Due to the low significance of most of the sources, only for 3 of them we found a significant variability, with values of $F_{\rm var}$ of $\sim$0.2–0.3, which is consistent with what found by [20] studying a sample consisting of the 20 brightest BAT AGN. This seems to show that on a monthly timescale the hard X-ray variability of NLS1s is not stronger than that of BLS1s, contrarily to what seen at lower energies.

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

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5. Conclusions

From the analysis of the average *INTEGRAL* IBIS/ISGRI spectrum of a sample of 14 NLS1s we confirmed that also at hard X-rays their spectrum is steeper than that of BLS1s. This might be due to different values of Γ or to different energies of the cutoff. The fact that up to ~ 40 keV the average spectrum of NLS1s is consistent with that of BLS1s favors the hypothesis that the photon indices are consistent, while the energy of the cutoff is lower for NLS1s. Consistent photon indices might be due to a bias towards low values of Γ of our hard X-ray selected sample. At hard X-rays NLS1s do not appear to be more variable than BLS1s. We also found that both luminosity and column density distributions are significantly different between the NLS1s and BLS1s, with the former having lower luminosities and lower values of the hydrogen column density.

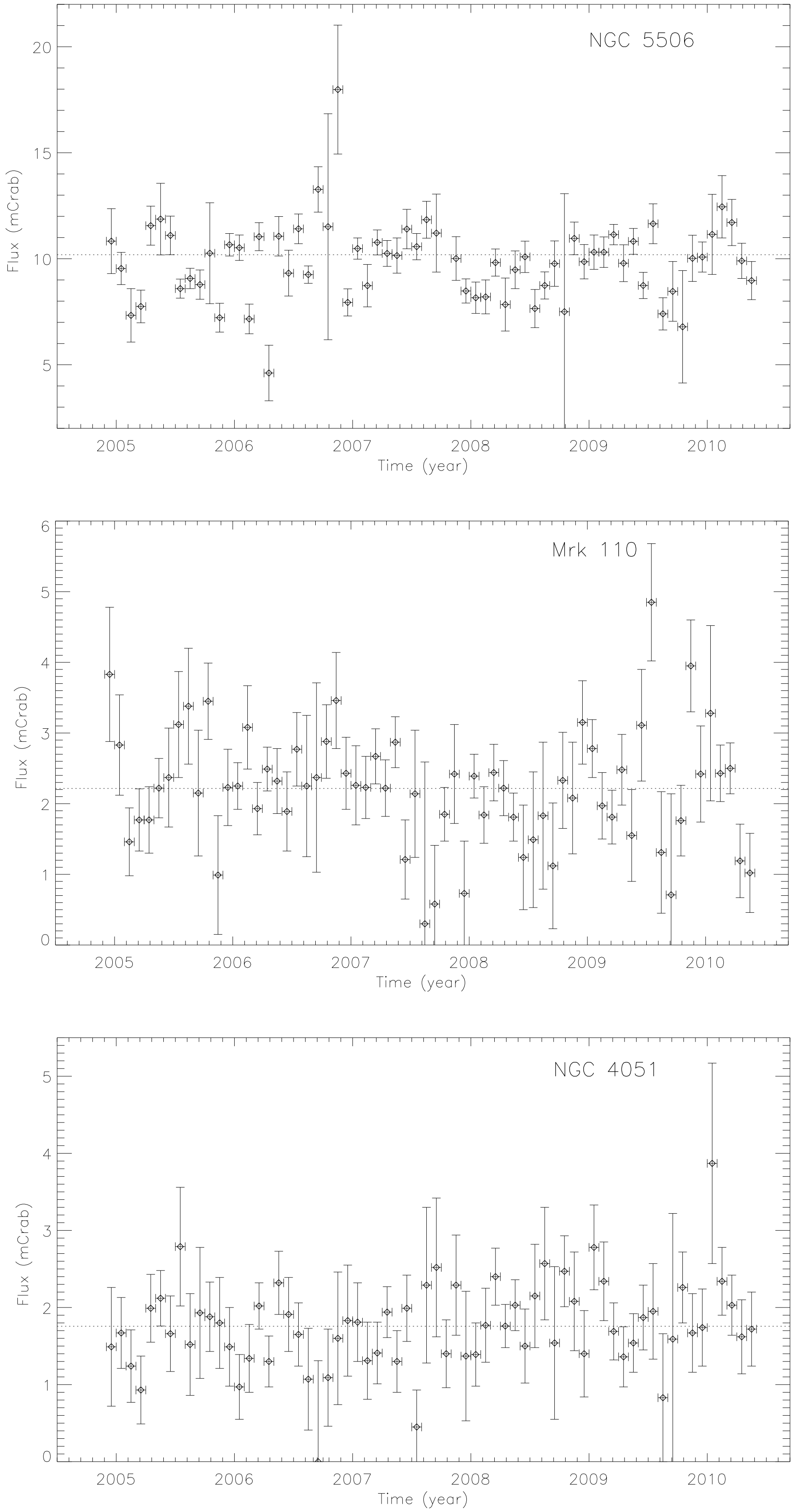

Figure 6: *Swift/BAT* 30-days binned light curves of NGC 5506, Mrk 110 and NGC 4051 in the 14–195 keV band. The dotted horizontal lines represent the average value for each object.

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