BATSE OBSERVATIONS OF THE PICCINOTTI SAMPLE OF AGN

A. Malizia
Department of Physics and Astronomy, University of Southampton, SO17 1BJ, England

L. Bassani
Istituto TeSRE/CNR, via Gobetti 101, 40129 Bologna, Italy

S. N. Zhang
University Space Research Association, Huntsville, AL 35806, USA

A. J. Dean
Department of Physics and Astronomy, University of Southampton, SO17 1BJ, England

W. S. Paciesas
University of Alabama, Huntsville, AL 35899, USA

G. G. C. Palumbo
Universitá di Bologna, Astronomy Department Bologna, Italy

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ABSTRACT

BATSE Earth occultation data have been used to search for emission in the 20-100 keV band from all sources in the Piccinotti sample, which represents to date the only complete 2-10 keV survey of the extragalactic sky down to a limiting flux of \(3.1 \times 10^{-11}\) erg cm\(^{-2}\) s\(^{-1}\). Nearly four years of observations have been analyzed to reach a 5\(\sigma\) sensitivity level of about \(7.8 \times 10^{-11}\) erg cm\(^{-2}\) s\(^{-1}\) in the band considered. Of the 36 sources in the sample, 14 have been detected above 5\(\sigma\) confidence level while marginal detection (3\(\leq\) \(\sigma\) \(\leq\)5) can be claimed for 13 sources; for 9 objects 2\(\sigma\) upper limits are reported. Comparison of BATSE results with data at higher energies is used to estimate the robustness of our data analysis: while the detection level of each source is reliable, the flux measurement maybe overestimated in some sources by as much as 35\%, probably due to incomplete data cleaning. Comparison of BATSE fluxes with X-ray fluxes, obtained in the 2-10 keV range and averaged over years, indicates that a canonical power law of photon index 1.7 gives a good description of the broad band spectra of bright AGNs and that spectral breaks preferentially occur above 100 keV.

Subject headings: X-ray, gamma-rays, active galaxies
1. Introduction

The only statistically complete and large sample of X-ray sources in the energy range 2-10 keV was obtained using data from the A-2 experiment on the HEAO-1 satellite (Piccinotti et al. 1982). This instrument performed a survey of 8.3 sr of the sky (65.5% coverage) at $|b| \geq 20^\circ$. Sources have been included in the catalogue if detected with a significance greater than or equal to $5\sigma$. The Piccinotti sample contains 85 sources (excluding the LMC and SMC sources) down to a limiting flux of $3.1 \times 10^{-11}$ erg cm$^{-2}$ s$^{-1}$. Of the 68 objects of extragalactic origin, 36 have been identified with active galaxies while the remaining sources were found to be associated with clusters of galaxies. The AGN sample is composed of 30 Seyfert galaxies (of which 23 are of type 1 and 7 of type 2), one starburst galaxy (M82), 4 BL Lac objects and one QSO (3C 273). Some objects which were left unidentified in the original Piccinotti list are now identified (Miyaji and Boldt 1990, Giommi et al. 1991, Fairall, McHardy and Pye 1982); these are H0111-149 (MKN1152, $z=0.0536$), H0235-52 (ESO198-G24, $z=0.045$), H0557-385 (IRAS F05563-3820, $z=0.034$), H0917-074 (EXO0917.3-0722, $z=0.169$), H1829-591 (F49, $z=0.02$) and H1846-768 (1M1849-781, $z=0.074$). Only one object (H1325-020) is still unidentified but it is probably associated to a galaxy cluster (A1750, Marshall et al. 1979) and therefore has been excluded from the present study. Three objects in the sample have the X-ray emission contaminated by a nearby source (IIIIZW2 by the visual binary HD560, Tagliaferri et al. 1988, IRAS F05563-3820 by the BL Lac object EXO055625- 3838.6, Giommi et al. 1989 and 3C445 by the cluster of galaxies A2440, Pounds 1990); however, since these nearby objects should give a negligible contribution to the emission above 20 keV, none of these sources have been excluded from the present analysis.

The Piccinotti sample is the hard X-ray selected sample of AGN best studied at all wavelengths below 10-20 keV and as such has been used to study AGN X-ray spectral characteristics, LogN-logS relation and luminosity function and hence to determine the
active galaxy contribution to the cosmic diffuse X-ray background in the 2-10 keV energy range. In the X-ray band most of the AGNs in the sample have been observed several times individually with different space borne experiments. Spectral data in the 2-10 keV range obtained over the last 20 years has been summarized in Ciliegi et al. (1993), Malaguti et al. (1994) and Malizia et al. (1997) for all objects except H0557$-$385 and H0917$-$074; the spectrum of the former can be found in Turner et al. (1996) while no spectral data have so far been reported for the latter object. More recently, intrinsic absorption and soft excesses have been studied for 31 of the Piccinotti sources (the 4 BL Lacs and the starburst galaxy M82 were not considered) using all-sky survey data from the ROSAT satellite in the 0.1-2 keV band (Schartel et al. 1997). A systematic study of the X-ray variability of the sample has been performed by Turner & Pounds (1989), Giommi et al. (1990) and Grandi et al. (1992) with the Low Energy (LE) (0.05-2 keV) and Medium Energy (ME) (2-50 keV) experiments onboard EXOSAT. Only in the last few years, high energy observations of individual objects in the sample started to be performed. Prior to CGRO and BeppoSAX, a handful of objects were detected above 10 keV by balloon borne telescopes, HEAO A-4 and Sigma/GRANAT (Rothschild et al. 1983, Bassani et al. 1985, Bassani et al. 1993). More recently, data on most of these galaxies have been obtained both by OSSE/CGRO and BeppoSAX/PDS. 27 of the Piccinotti objects has so far been observed by OSSE, 11 with detection above $\geq 5\sigma$ level (McNaron-Brown et al. 1995 and Johnson, 1997 private communication) while BeppoSAX reported high energy emission from at least 16 sources in the sample (Matt 1998, Bassani et al. 1998, Cappi et al. 1998, Pian et al. 1998, Antonelli et al. 1998, BeppoSAX public archive). The BATSE data reported here provide, for the first time, a systematic coverage at high energies of the whole sample. In this first work BATSE data in the 20-100 keV range are reported for all sources (presentation of light curves and images are postponed to a future paper) and, whenever possible, comparisons with previous soft and hard X-ray data have been performed.
2. Observations and Results

The Burst and Transient Source Experiment (BATSE) onboard CGRO, is the first all-sky monitor operating from 20 keV up to several MeV. The BATSE daily monitoring sensitivity is \( \sim 100 \) mCrab, implying that sensitivities of the order of a few mCrab could be obtained by integrating the data over a period of a few years, if systematic errors can be kept sufficiently small (McCollough et al. 1996). The data used in this work were collected by the Large Area Detectors (LADs) in Earth occultation mode (Harmon et al. 1992); this mode allows to measure a source flux by looking at changes in the LAD background rates when the object under investigation rises from and sets behind the Earth. A pair of rising and setting steps are generated during each 90 minute satellite orbit implying that a large number of steps must be summed to extract signal from weak sources such as extragalactic objects. The Earth occultation method allows a nearly complete sky coverage (sources whose declination is \( \leq 35 \) degrees are always occulted, while for other objects the coverage efficiency is 90\% or better) and so it is ideal to study moderately large samples of sources. Since the occultation technique reaches its peak sensitivity below \( \sim 140 \) keV, the search for emission by AGN in the Piccinotti sample was carried out in the range between 20 and 100 keV.

BATSE data from nearly four years of observations (November 93 - September 97) have been analyzed to extract a signal from sources in the Piccinotti sample. Interference from bright sources flaring or occulted at the same time of the object being studied are the major source of systematic errors in the flux measurement and so careful cleaning of the data is necessary before estimating the flux. Two types of cleaning procedures have been applied to the data. First the median statistics has been applied to remove about 5\% of data points as outlier individual occultation steps; these outliers are generally due to pulsar activity in individual detectors. Second, contaminating objects in the limbs to the source being studied have been identified using a catalogue of flaring and bright objects.
detected at high energies. If present, these contaminating sources were included in the occultation step fit and consequently data corresponding to contaminating periods were removed. In 7 cases (ESO 103-G35, IC 4329A, MCG-6-30-15, MKN 501, NGC 4593, NGC 7172 and PKS 2155-304) contamination was found and the above procedure applied. Of course any interfering sources that are not taken into account (i.e. are not included in the database) will systematically increase the flux estimate. This maybe particularly important for sources closer than 5° to the galactic plane or within a cone of 45° around the galactic center up to 30° (Connaughton et al. 1998a). Since we are probing the extragalactic sky, only a handful of sources (ESO103-G35, ESO141-G55, Fairall 49 and MKN509) fall within the above cone and in any case, all of them are located just at the extreme boundaries of the cone and therefore they have not been excluded from the present analysis. Moreover, comparison of our fluxes with OSSE and BeppoSAX data for two of the above sources suggests that contamination from galactic objects was in these cases negligible.

Fluxes in the 20-100 keV energy band have been obtained by folding a single power law of photon index 1.75 for Seyfert galaxies, 3C273 and M82, and 2.25 for BL Lac objects, with the BATSE instrumental response function and then computing weighted mean flux values over the whole observation period. Although these mean estimates depend on the choice of the photon index, the differences in fluxes are of the order of 10-20% around the values reported in Table 1 for $\Delta \Gamma = \pm 0.25$.

Before proceedings with the discussion of our results and in view of the difficulties associated with the data analysis, it is important to search for possible systematic effects on the flux measurements. Two types of systematic errors are particularly relevant: those affecting the overall normalization (which are particularly important for the comparison with other instruments), and those affecting the size of the fluctuations (which are relevant to estimate the confidence level of a detection). Comparison of BATSE occultation results with contemporaneous observations with other CGRO instruments have indicated that the
BATSE flux values maybe systematically higher. In the most extensive study published to date, Much et al. (1996) found that the BATSE Crab Nebula flux was ~20% higher than OSSE flux in the same energy range. More recently, Parsons et al. (1998) compared BATSE measurements of NGC 4151 with those of OSSE and derived a BATSE/OSSE flux ratio of 1.45±0.08. In view of the relevance of the Parsons et al. study to the present one, we have performed a similar analysis on all the sample sources for which contemporaneous BATSE/OSSE data (kindly provided to us by the OSSE team, Johnson 1997, private communication) could be analyzed. The results of this analysis are summarized in the parameter R reported in Table 1. For every contemporaneous BATSE/OSSE observation we have estimated the relative flux ratio in the 20-100 keV band and than we have calculated R which represents the weighted mean value with its associated error of all the available flux ratios. The numbers in parentheses indicate how many periods were examined (first quote) and the total number of observation days analyzed over those periods (second quote). It is evident from Table 1 that R is ≥ 1 in most cases, the weighted mean value of R being 1.36 ± 0.03 (this value becomes 1.5 ± 0.13 if the two strongest sources, NGC4151 and 3C273, are removed). Thus our result confirms previous reports of a BATSE/OSSE normalization discrepancy (Much et al. 1996, Parsons et al. 1998) and further indicates that in the particular case of extragalactic studies the BATSE flux can be sistematically higher that the OSSE one by as much as 35%. The possible origin for this normalization problem is at the moment under investigation and will hopefully be solved in the near future. A possible explanation maybe source interference which is not taken into account in the data cleaning. This is an important problem to address if BATSE light curves are to be used to monitor bright source behaviour at high energies.

We have also compared BATSE data to published BeppoSAX observations, although in this case the comparison is hampered by the lack of simultaneous data. Nevertheless we get a BATSE/SAX flux ratio in the range 1.6-1.8 which again indicates that our fluxes maybe
overestimating the source high energy emission. However, since for individual sources the discrepancies found can be less than quoted and in fact $\sim 1$ (see for example 3C273 and other sources in Table 1), no correction is applied to the BATSE data in the present work. Furthermore, as the errors too are effected in the same way as the fluxes, this normalization problem has no impact on the detection level of a given source.

The effects of systematic errors have also been carefully considered by examining "blank fields" randomly distributed around the sky. It was found that while the flux values for each field were consistent with the quoted errors, the spread around zero of the mean fluxes from a large number of these empty fields was about 80% higher than would be expected by the statistical errors alone (Stephen 1998, private communication). For this reason all the errors on the mean fluxes were adjusted by 80% so as to be conservative in the source detection estimate. This estimate of the systematic errors is slightly higher than the 65% obtained by Connaughton et al. (1998a), but compatible given the difference in the number of fields analysed.

Table 1 lists all sources contained in the sample together with their optical classification, X-ray data in the 2-10 keV band, a compendium of the results of the BATSE data analysis (flux and significance of detection) and the BATSE/OSSE flux ratio. Significant detection at $\geq 10\sigma$ level has been found for three sources (NGC 4151, 3C 273 and NGC5506), while at the $5\sigma$ level the number of detected sources grows to 14. Marginal detections ($3 < \sigma < 5$) can be claimed for 13 sources while only 9 galaxies were observed below the 3 $\sigma$ confidence level.

3. Discussion

The main result of this work is the detection of high-energy emission from the majority of the sample sources. Comparison between OSSE and BATSE data indicates that 6
objects are here reported as hard X-ray emitting sources for the first time: ESO198-G24, H0917-074, ESO 103-G35, H1846-786, 3C 445 and MKN1152, all detected above the 3 $\sigma$ confidence level; of these only ESO 103-G35 has been reported as a high energy source by BeppoSAX (Antonelli et al. 1998). It is also interesting to find out that 5 out of 8 Seyferts 2 in the sample have been detected, in agreement with the expectation of the unified theory, which predicts similar energy output for type 1 and type 2 Seyferts at high energies. Particularly interesting is also the BATSE detection of two BL Lac objects out of four in the sample: MKN 501 and PKS 2155-304. Due to the steepness of their spectra compared to Seyferts, BL Lacs have less probability of being detected by BATSE unless higher than expected brightness was present during BATSE monitoring (see below).

In order to assess the reliability of our results and to investigate the approximate spectral shape of AGN in the BATSE energy band, a comparison with soft X-ray fluxes has been performed. BATSE flux estimates, however, are the result of a long integration period (years) and thus represent averaged values over this period, while observations with pointed instruments provide instantaneous flux measurements. This has been taken into account by using in the 2–10 keV band mean flux values as estimated from data in the literature (Ciliegi et al. 1993, Malaguti et al. 1994, Malizia et al. 1997, Polletta et al. 1996). The errors on this mean flux has been set equal to the observed range of X-ray variability or VR. In Figure 1, BATSE flux values are plotted against these 2-10 keV flux measurements. Lines plotted in the figure correspond to the ratio expected for two values of the photon index (1.5 and 2) under the hypothesis of a single power law continuum from 2 to 100 keV. It is interesting to find that a good fraction of galaxies fall within the region constrained by these two spectral indices, particularly if the range of X-ray flux variability is taken into account. More specifically the broad band (2-100 keV) power law slope can be estimated from the fluxes emitted in the two bands: while the average photon index is 1.7, the weighted mean value is 1.6±0.1 (considering only detection above 3$\sigma$ and excluding BL Lacs); removal of
NGC4151 and 3C273 from the sample does not change this mean. Decreasing the BATSE fluxes by the amount required by the BATSE/OSSE comparison would make this mean photon index slightly steeper. Therefore the canonical 1.7 power law which best represents the X-ray data gives also a good description of the spectrum in the 20-100 keV band. This result indicates that the reflection component which is responsible for flattening the intrinsic spectrum in the 2-10 keV band, is relevant also above 20 keV and present in most sample sources. Furthermore, BATSE observations imply that spectral breaks and/or steepening must occur preferentially above about 100 keV for consistency with our findings. This is in line with BeppoSAX results on Seyfert galaxies which locate the spectral cutoff typically at energies $\geq 100$ keV (Matt 1998, Bassani et al. 1998).

A couple of exceptions are however worthy of a note. Two sources, MCG-6-30-15 and NGC2992, are located in the region characterized by spectral indices greater than 2.0 (or, alternatively, in these sources the BATSE flux is underestimated, which is a bit surprising in view of the above discussion). NGC2992 is however compatible with flatter indices, if one considers the source’s large range in variability and, in particular, the gradual decline in flux by a factor of $\sim 20$ monitored over the last 10 years (Polletta et al. 1996): by sampling the last part of this period BATSE probably underestimates the source average flux. The case of MCG-6-30-15 is less obvious and deserves further investigation: either the source was dimmer during the BATSE coverage with respect to previous 2-10 keV observations or a break below 100 keV (Molendi et al. 1998) must be postulated. Since BeppoSAX observation of this source locates the break at energies $\geq 100$ keV (Molendi et al. 1998), the first alternative is more plausible suggesting that BATSE can indeed be used as a monitor of bright source states. The location of MKN501 and 2A 1219+305 is also peculiar as these two objects have unusually flat spectra for BL Lac objects (Ciliegi et al. 1995). While the case of 2A 1219+305 is less stringent, the detection being only an upper limit, the case of MKN501 is particularly interesting. Strong flaring activity has been
reported from this source at high energies during the BATSE monitoring period (Pian et al. 1998 and Catanese et al. 1997, Lamer et al. 1998); analysis of the BATSE light curve indicates indeed that flare like events are present along with a gradual increase in flux during April-July 1997 (Connaughton et al. 1998a,b). During at least one such event (in April) the source spectrum was flatter than previously reported (Pian et al. 1998). Given the peculiar behaviour observed during BATSE coverage, a proper comparison between low and high energy bands should use contemporaneous data.

Finally, BATSE results have been compared with previous studies of the average AGN flux at high energies; the average flux of the Seyfert galaxy population as a whole has been found to be \((1.74 \pm 0.05) \times 10^{-5}\) photons/cm\(^2\) s keV in the 20-100 keV band and if strong sources such as NGC 4151, 3C 273 and IC 4329A are excluded, the mean flux reduces to \((1.24 \pm 0.05) \times 10^{-5}\) photons/cm\(^2\) s keV. Dividing the sample in classes gives a mean flux of \((1.88 \pm 0.05) \times 10^{-5}\) photons/cm\(^2\) s keV for Seyfert 1, \((1.31 \pm 0.11) \times 10^{-5}\) photons/cm\(^2\) s keV for Seyfert 2 and \((1.03 \pm 0.19) \times 10^{-5}\) photons/cm\(^2\) s keV for BL Lac objects, in agreement with the results of Maisack, Wood and Gruber (1994) based on HEAO A4 data, albeit a 40% reduction in the BATSE fluxes would improve the comparison. Also, if only the radio quiet Seyfert 1 galaxies in the sample (12 objects) are taken into account, the average flux is \((1.22 \pm 0.08) \times 10^{-5}\) photons/cm\(^2\) s keV, compatible within errors with the value obtained by Gondek et al. (1996) for the same class of objects; in this case no correction to a lower flux level is required by the comparison. While the agreement found gives confidence to our data analysis (the level of each detection is a sound result, while the flux estimate maybe in some cases slightly overestimated) it also demonstrates the potential of BATSE for cumulative studies of selected samples of objects for example in search of a population of objects bright at high energies. Down to a limiting flux of \(7.8 \times 10^{-11}\) erg cm\(^{-2}\) s\(^{-1}\) BATSE has been able to detect 14 objects above 5 \(\sigma\) level over 8.2 sr. This is to be considered a lower limit to the number of high energy emitting AGN as highly absorbed
objects, i.e. objects missed in the Piccinotti survey for their absorption in excess of $10^{24}$ cm$^{-2}$ but visible above 10 keV (Bassani, Cappi, Malaguti 1998), are probably not included. This suggests that an improvement in sensitivity of a factor of $\sim 10$ as foreseen for the next generation of high energy telescopes such as INTEGRAL (Winkler 1996) would allow more than 600 objects to be visible over the entire sky at $\geq 5 \sigma$ level.

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Table 1.

| Source        | Type   | $F_{\text{MEAN}}^\dagger$ (2-10)keV | VR$^\dagger$ | Low Energy | High Energy |
|---------------|--------|-------------------------------------|--------------|------------|-------------|
| III ZW 2      | Sey 1  | 2.93                                | 0.64         |            | 4.88±1.62   |
| MKN 1152      | Sey 1.5| 2.02                                | 1.22         | 5.99±1.51  |
| FAIRALL 9     | Sey 1  | 2.89                                | 2.15         | 3.80±1.70  |
| NGC 526A      | Sey 2  | 3.13                                | 2.43         | 12.44±1.54 |
| MKN 590       | Sey 1.2| 1.97                                | 0.94         | 6.75±1.47  |
| ESO 198−G24   | Sey 1  | 3.30                                | 1.31         | 5.27±1.66  |
| 3C 120        | Sey 1  | 3.94                                | 1.26         | 4.84±1.58  |
| PKS 0548−322  | BL Lac | 2.73                                | 1.17         | <3.76      |
| H0557−385     | Sey 1  | 3.17                                | 1.75         | 4.74±1.53  |
| H0917−074     | Sey 1  | 1.88                                | 1.08         | 5.63±1.55  |
| NGC 2992      | Sey 2  | 5.03                                | 4.58         | <3.18      |
| M 82          | SB     | 2.52                                | 0.16         | 5.94±1.12  |
| NGC 3227      | Sey 1.5| 3.15                                | 2.35         | 11.26±1.53 |
| NGC 3783      | Sey 1  | 4.69                                | 3.35         | 13.00±1.64 |
| NGC 4151      | Sey 1.5| 22.55                               | 15.05        | 77.46±1.59 |
| 2A 1219+305   | BL Lac | 2.98                                | 1.38         | 5.70±2.29  |
| 3C 273        | QSO    | 11.68                               | 6.14         | 39.13±1.59 |
| NGC 4593      | Sey 1  | 3.17                                | 1.17         | 9.81±1.59  |
| MCG−6−30−15   | Sey 1  | 5.77                                | 1.51         | <4.30      |
| IC 4329A      | Sey 1  | 12.15                               | 7.05         | 19.44±1.99 |
| NGC 5506      | Sey 1.9| 6.52                                | 4.75         | 19.16±1.60 |

Notes:

$^\dagger$ Mean flux in the specified energy range.

$^\star$ Significant at the 90% confidence level.
Table 1—Continued

| Source     | Type | $F_{MEAN}^{†}$ (2-10)keV | $VR^{†}$ | $F_{BATSE}^{†}$ (20-100)keV | $N_{σ}^{BATSE}$ | $R^{⋆}$ |
|------------|------|--------------------------|----------|-----------------------------|----------------|---------|
| NGC 5548   | Sey 1| 4.35                     | 2.37     | 10.53±1.58                  | 6.67           | 1.45±0.63 (3-26) |
| MKN 501    | BL Lac | 3.40                  | 1.25     | 10.31±2.77                  | 3.71           | ⋯       |
| FAIRALL 49 | Sey 2 | 1.94                     | 1.43     | 3.98±1.86                   | 2.14           | ⋯       |
| ESO 103−G35| Sey 2 | 2.09                     | 0.89     | 7.92±1.86                   | 4.26           | ⋯       |
| H1846−786  | Sey 1 | 2.46                     | 0.76     | 5.99±1.76                   | 3.39           | ⋯       |
| ESO 141−G55| Sey 1 | 3.26                     | 0.44     | <3.50                       | ⋯              | ⋯       |
| MKN 509    | Sey 1 | 4.41                     | 1.29     | 12.47±1.52                  | 8.18           | 0.96±0.6 (2-20) |
| PKS 2155−304| BL Lac | 9.29                   | 5.21     | 7.70±1.94                   | 3.97           | 1.19±0.82 (2-14) |
| NGC 7172   | Sey 2 | 3.06                     | 1.29     | 8.00±1.55                   | 5.15           | 1.16±0.37 (3-26) |
| NGC 7213   | Sey 1 | 3.66                     | 1.34     | 3.39±1.65                   | 2.05           | 2.23±1.5 (1-7) |
| 3C 445     | Sey 1 | 2.28                     | 1.09     | 12.15±1.54                  | 7.88           | ⋯       |
| NGC 7314   | Sey 1.9| 2.76                  | 1.46     | 4.19±1.58                   | 2.66           | ⋯       |
| NGC 7469   | Sey 1 | 3.02                     | 1.22     | 7.77±1.51                   | 5.15           | 2.39±2.05 (1-7) |
| MCG−2−58−22| Sey 1.5| 4.08                 | 2.32     | 7.53±1.53                   | 4.93           | ⋯       |
| NGC 7582   | Sey 2 | 3.60                     | 3.00     | 8.97±1.65                   | 5.43           | <2.14 (1-7) |

$^{(†)}$ = flux in units of $10^{-11}$ erg cm$^{-2}$ s$^{-1}$.

BATSE fluxes are the weighted mean calculated over nearly four year of observations

$^{(‡)}$ = fluxes variability range in the 2-10 keV energy band

$^{(⋆)}$ = weighted mean value of the BATSE/OSSE flux ratios in the 20-100 keV with its associated error for contemporaneous observations. The numbers in parentheses indicate how many periods were examined (first quote) and the total number of observation days analyzed per those periods (second quote).

** upper limits are at 2σ level
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Fig. 1.— BATSE 20-100 keV weighted mean fluxes on a ∼ 3 years of observations with their relative errors, are plotted against 2-10 keV average fluxes. The horizontal bars in the figure are the 2-10 keV flux ranges (minimum and maximum value found in the literature). Lines plotted correspond to the ratio between fluxes expected for various values of photon index under the hypothesis of a single power law continuum from 2 to 100 keV. Although 3C445 has a slope flatter than 1.5 this is consistent with recent X-ray measurements (Sambruna et al. 98).