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High Energy NLSy1 Galaxies

F. Panessa*
Istituto di Astrofisica Spaziale e Fisica Cosmica (IASF-INAF), via del Fosso del Cavaliere 100, 00133 Roma, Italy
E-mail: `francesca.panessa@iasf-roma.inaf.it`

A. De Rosa
Istituto di Astrofisica Spaziale e Fisica Cosmica (IASF-INAF), via del Fosso del Cavaliere 100, 00133 Roma, Italy
E-mail: `alessandra.derosa@iasf-roma.inaf.it`

L. Bassani
Istituto di Astrofisica Spaziale e Fisica Cosmica (IASF-INAF), Via P. Gobetti 101, 40129 Bologna, Italy
E-mail: `bassani@bo.iasf.cnr.it`

A. Bazzano
Istituto di Astrofisica Spaziale e Fisica Cosmica (IASF-INAF), via del Fosso del Cavaliere 100, 00133 Roma, Italy
E-mail: `angela.bazzano@iasf-roma.inaf.it`

A. Bird
School of Physics and Astronomy, University of Southampton, Southampton, SO17 1BJ, UK
E-mail: `ajb@astro.soton.ac.uk`

R. Landi
Istituto di Astrofisica Spaziale e Fisica Cosmica (IASF-INAF), Via P. Gobetti 101, 40129 Bologna, Italy
E-mail: `landi@iasfbo.inaf.it`

A. Malizia
Istituto di Astrofisica Spaziale e Fisica Cosmica (IASF-INAF), Via P. Gobetti 101, 40129 Bologna, Italy
E-mail: `malizia@iasfbo.inaf.it`

M. Molina
Istituto di Astrofisica Spaziale e Fisica Cosmica (IASF-INAF), Via Bassini 15, 20122 Milano, Italy
E-mail: `molina@iasf-milano.inaf.it`

G. Miniutti
Centro de Astrobiologia (CSICĐINTA); LAEFF,P.O: Box78, E-28691, Villanueva de la Canada, Madrid, Spain
E-mail: `gminiutti@cab.inta-csic.es`

P. Ubertini

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Istituto di Astrofisica Spaziale e Fisica Cosmica (IASF-INAF), via del Fosso del Cavaliere 100, 00133 Roma, Italy
E-mail: `pietro.ubertini@iasf-roma.inaf.it`

Narrow Line Seyfert 1 galaxies (NLSy1) are among the most interesting class of active nuclei. Their observational properties suggest that they are high accretion rate systems probably associated with relatively smaller back hole masses with respect to classical Seyfert 1 galaxies. However, the number of known NLSy1 detected above 10 keV is small notwithstanding the importance of the high energy data to discriminate between the major compelling models. Here we present a detailed study of a sample of 15 NLSy1 detected above 10 keV by INTEGRAL/IBIS. An accurate broad-band analysis has been performed using INTEGRAL data combined with XMM-Newton, Suzaku and Swift. The high energy spectral properties have been related to their black hole mass and accretion parameters.

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*Speaker.

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1. Introduction

Narrow Line Seyfert 1 (NLSy1) are AGN with optical spectral properties similar to those of Seyfert 1 galaxies (Broad Line Seyfert 1, BLSy1), except for having very the narrowest Balmer lines and strongest optical FeII lines (Osterbrock & Pogge 1985)7. The classical definition of NLSy1 relies on three simple criteria: (i) the full width half maximum (FWHM) of the H_β line $<$ 2000 km s^{-1}; (ii) the [OIII] λ5007/H_β ratio $<$3; and (iii) unusually strong FeII.

The most extreme characteristics of NLSy1 are seen in the X-ray domain (Gallo 2006). A strong and variable soft excess emission below 1$\sim$ keV is present (George et al. 2000, Boller et al. 1996, Turner et al. 1999) more frequent than in BLSy1 (Leighly 1999). The 2-10 keV spectral slope is usually steeper in NLSy1 (Leighly 1999, Brandt et al. 1997) and a sharp spectral drop at about 7 keV has been observed in some objects (Uttley et al. 2004, Longinotti et al. 2003, Boller et al. 2003). The complex NLSy1 X-ray spectrum has been explained in terms of relativistic blurred reflection (e.g., Fabian et al. 2004), partial covering absorption (e.g., Tanaka et al. 2004) or reflection from ionized material (e.g., Gierliński & Done 2004).

A possible interpretation for the peculiar observational properties of NLSy1 is that these systems are accreting close to their Eddington limit, suggesting that, compared to their BLSy1 counterparts, they should host smaller black hole masses, as measured in the majority of the sources (Wandel et al. 1999, Grupe & Mathur 2004). Under the assumption that the H_β emitting region is gravitationally bounded to the central black hole, small black hole masses help in explaining the narrow emission lines observed in these objects. Recently, the interest on NLSy1 is further increasing due to the detection of gamma-ray emission from four NLSy1 with Fermi (Abdo et al. 2009) suggesting that NLSy1 may also form a powerful radio jet and at the same time be powered by black holes of moderate masses (Yuan et al. 2008).

A wavelength range where NLSy1 have been poorly investigated so far is hard X-rays (above 10 keV), where only studies on sparse objects are available. *BeppoSAX* observations of a small sample of NLSy1 detected hard X-ray emission in only 2 out of 7 sources (Comastri 2000). Suzaku is now providing detailed broad-band studies of selected NLSy1 (e.g., Miniutti et al. 2009, Terashima et al. 2009). Recent hard X-ray surveys performed by the IBIS instrument (Ubertini et al. 2003) on board *INTEGRAL* (Winkler et al. 2003) and the BAT instrument (Burrows et al. 2005) on board *Swift* (Geherels et al. 2004) are imaging the hard X-ray sky providing a number of sources detected for the first time at these energies with half of them newly discovered (Malizia et al. 2010, Landi et al. 2010, Tueller et al. 2009).

Indeed, the fourth IBIS survey (Bird et al. 2010) has allowed the detection of more than 700 hard X–ray sources over the whole sky above 20 keV, down to an average flux level of about 1 mCrab and with positional accuracies ranging between 0.2 and $\sim$5 arcmin. Among the detected AGN by IBIS, a small sample of NLSy1 is identified. A first analysis of the hard X-ray properties of a sample of five NLSy1 detected by IBIS has been presented in Malizia et al (2008), which combined *Swift*/XRT and *INTEGRAL*/IBIS spectra. Increasing the number of NLSy1 detected at $>$ 10 keV allows a better characterization of their hard X-ray emission, it is therefore important to study these objects on a statistical basis.

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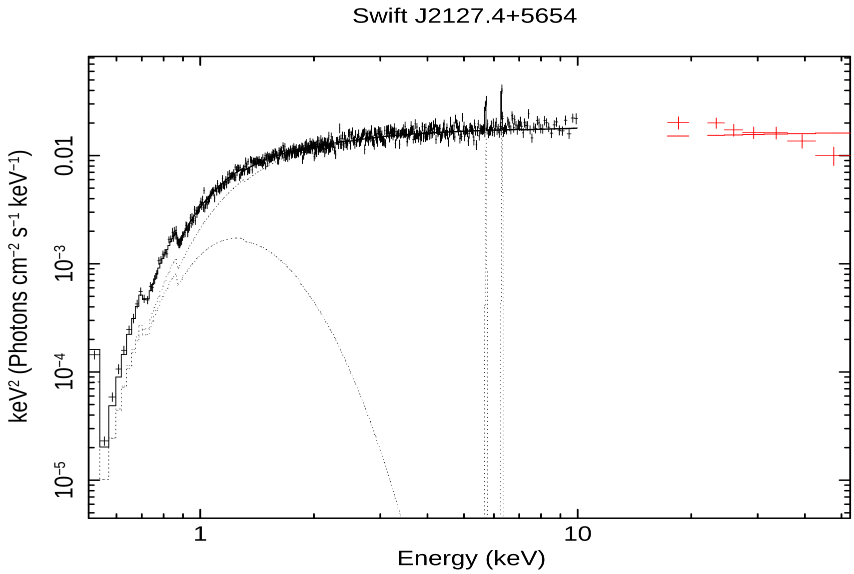

Figure 1: Broad-band *XMM-Newton* and *INTEGRAL* best–fit spectra.

2. The sample

Here we present the broad-band X-ray properties of a sample of 15 NLSy1 detected by *INTEGRAL* and present in the fourth IBIS catalogue (Bird et al. 2010) plus one NLSy1 (Swift J0923.7+2255) detected by *Swift*/BAT, for a total of 15 hard X-ray selected NLSy1. New *XMM-Newton* datasets for 7 NLSy1 of the sample (six of them observed for the first time below 10 keV with *XMM-Newton*) have been combined with the *INTEGRAL* data to obtain a wide energy range up to 150 keV. In 4 objects, *XRT* data have been used below 10 keV, while for IGR J16426+6536, only an XRT detection is available. Most of the IGR sources in the sample have been classified during the optical follow-up campaigns which are on-going to identify the *INTEGRAL* IBIS sources (Masetti et al. 2010 and references therein).

See the web page `http://www.iasfbo.inaf.it/extras/IGR/main.html` for the information about the *INTEGRAL* sources identified using optical or near-infrared (NIR) observations.

3. The broad-band data

The IBIS/*INTEGRAL* data used in this work have been collected in the 4th IBIS survey (Bird et al., 2010) consisting of 7355 pointings (called Science Windows, ScW, lasting about 2000 sec each) performed from the beginning of the Mission in November 2002 up to April 2008 and including both all available public and Core Programme data. IBIS/ISGRI images for each available pointing were generated in various energy bands using the ISDC off-line scientific analysis software OSA (Goldwurm et al. 2003) version 7.0. Then all images have been mosaicked to create significance map at revolution level (each orbit lasting about 3 days) and for the all available pointings. Count rates at the position of the source were extracted from individual images in order to provide light

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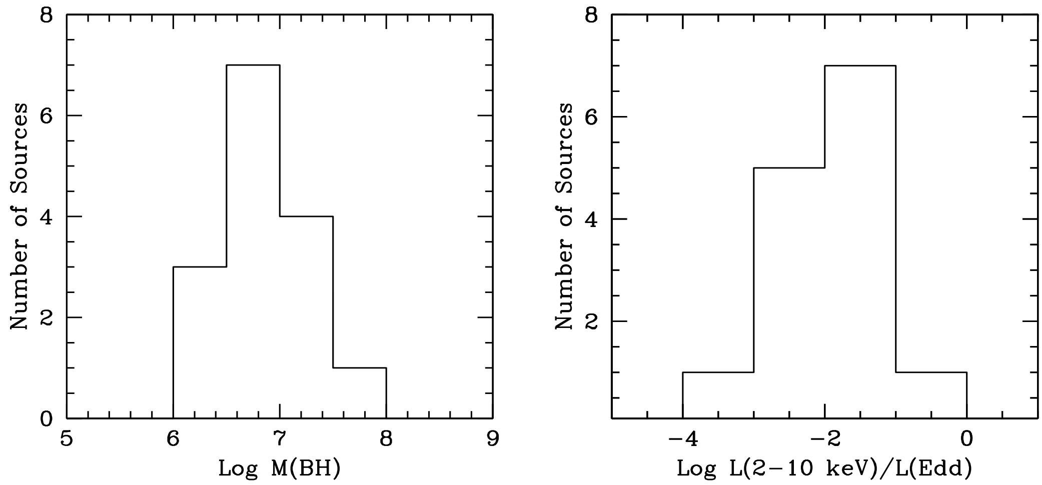

Figure 2: Left panel: Log black hole mass distribution in NLSy1. Right panel: Log $L_{2-10keV}/L_{Edd}$ ratio distribution.

curves in various energy bands; from these light curves, average fluxes were then extracted and combined to produce an average source spectrum (see Bird et al. 2010 for details).

XMM-Newton/*XRT* and *INTEGRAL* spectra have been combined to obtain a 0.3-150 keV broad-band spectrum. Since the *XMM-Newton*/*XRT* and *INTEGRAL* observations are not simultaneous, a cross-calibration constant C is left free to vary to take into account possible cross-calibration mismatches between the two instruments but more importantly in these objects, to consider variability effects. With the aim of characterizing broadly the spectral properties of the sample, to a baseline model composed of a simple power-law with absorption fixed at the Galactic value, we have added extra components to model spectral residuals.

4. Results

NLS1s usually exhibit very steep spectral slopes, therefore hard–X–ray bright sources are very rare among this class. Here we present the averaged spectral properties of the first sizable sample of NLSy1 detected at hard X-rays. Hard X-ray NLSy1 look very heterogeneous in their broad-band properties, displaying a broad range of hard X-ray (20-100 keV) photon indeces, flatly distributed from quite flat ($\sim$ 1.5) to very steep ($\sim$ 3.5) slopes, at these energies no clear separation between the BLSy1 and NLSy1 slopes distributions is found (although the statistics is still limited for NLSy1). In only one source, SwiftJ2127.4+5654 (see Figure 1), a high energy cut-off was constrained and a relatively low value ($E_{cut-off} \sim$ 50 keV) was found, confirming previous Suzaku and IBIS measurements (Miniutti et al. 2009, Malizia et al. 2008). The hard X-ray selection is not efficient in detecting strong soft X-ray NLSy1, indeed only two sources (Swift J0923.7+2255 and IGR J19378-0617) show a dominant soft X-ray emission while the presence of fully or partially covering absorption is more frequent (in four out of eleven sources analyzed in this work). When the spectral quality is good (i.e., *XMM-Newton* data), we almost always detect the presence of an Fe line (from moderately broad to narrow profiles). A proper determination of the reflection strength

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is limited by the non simultaneity of the X-ray and hard X-ray observations, this is particularly true in this class of sources where X-ray variability (in flux and spectrum) is strong, both at short and long terms, as here demonstrated by the *XMM-Newton* light curves and in those source where multiple observations were available. Variability is significant also at hard X-rays as deduced from a comparison between the *INTEGRAL* and BAT average fluxes, i.e., in half of the sample a flux variation $> 30\%$ is found.

The peculiar properties of NLSy1 have been commonly associated to the small black hole masses and relative high Eddington ratios. Black hole masses are usually estimated through mass-radius relations, the latter derived from the optical continuum luminosity (Kaspi et al. 2000), however it must be taken in mind that large uncertainties affect these estimates. The distribution of the black hole masses in our sample (Figure 2, left panel) peaks at $\sim 10^7$ $M_\odot$, confirming the findings that NLSy1 host preferentially small black holes and possibly suggesting that the hard X-ray origin of the sample is not introducing any particular selection effect in the black hole mass range. This result is similarly found in an X-ray selected sample where Bianchi et al. (2009) have shown that NLSy1 have the smallest BH masses when compared to BLSy1. The Eddington ratios derived from the 2-10 keV luminosity and Eddington luminosity ratio (Figure 2, right panel) also point to highly accreting systems.

We estimate that the fraction of NLSy1 in the hard X-ray sky is about 15% of the type 1 AGN population, in agreement with the optically selected sample fraction. NLSy1 in our sample are radio sources (when data are available), however only one source, 1H 0323+342, is confidently radio-loud.

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