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The radio and X-ray correlation in a sample of hard X-ray selected AGN

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PoS(Extremesky 2011)049

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The accretion-ejection mechanism acting in Active Galactic Nuclei (AGN) is one of the main astrophysical open questions. A strong correlation between the nuclear 2-10 keV X-ray versus core radio luminosities suggests that the accretion flow and the radio source are strongly coupled both in radio-quiet AGN and in radio-loud AGN. We approach this topic from the hard X-ray point of view by discussing the radio versus X-ray correlation in a complete sample of INTEGRAL AGN, selected between 20-40 keV. A strong correlation between the 20-100 keV and NVSS radio luminosities is found, which is more significant than the correlation of the 2-10 keV and radio luminosities. When computed for an optically selected sample of local AGN, the correlation slope is steeper with respect to the one obtained for the INTEGRAL AGN sample. These results indicate that the X-ray versus radio correlations hold also for relatively high luminosity AGN, suggesting that in efficient accretion systems the two source of emission are in someway connected.

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

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1. Introduction

Active galactic nuclei (AGN) emit continuum radiation from the radio to the hard X-rays, and sometimes gamma-rays. The X-ray and hard X-ray emission in AGN is thought to arise from a non-thermal mechanism such as the Comptonization of the optical-UV disc continuum by hot thermal or non-thermal electrons residing in a magnetically confined gas above the accretion disc (e.g., Haardt & Maraschi 1991). The radio emission has been classically associated with fast jets carrying relativistic electrons, emitting non-thermal synchrotron radiation. However, the fraction of AGN with powerful relativistic jets is only 10-20% of the entire AGN population (Kellermann et al. 1989), the majority of which is instead made up of Radio-Quiet (RQ) AGN, defined as having a radio loundness parameter R $\equiv$ L_{6cm} / $L_B \leq 10$. Typically RQ AGN show values of R concentrated between 0.1-1, while in radio-loud sources the R values range from 10 to 100 (Kellermann et al. 1989). Lately, Terashima & Wilson (2003) have introduced the X-ray radio-loudness parameter R_X $\equiv$ L_ν(6 cm)/L(2-10 keV). The use of the X-ray luminosity with respect to the optical one allows to avoid extinction problems which normally occur in the optical band and which could cause an overestimation of R. RQ AGN are therefore quiet in the radio band but not silent as, at some low flux level, they still emit radio waves (e.g., Ho & Ulvestad 2001). Radio images of RQ AGN confined the radio emission to arcsec scale and, at higher resolution such as those mapped by the VLBI images, significant compact radio emission on mas scales is found, which corresponds to fraction of pc for nearby AGN (e.g., Nagar et al. 2002, Anderson & Ulvestad 2005, Wrobel & Ho 2006). In RQ AGN the radio emission is mostly unresolved at arcsec scale, and often remains largely unresolved down to mas (Giroletti & Panessa 2009). The origin of the radio emission in RQ remains still unclear; it could be ascribed, for instance, to a low-power jet (e.g., Miller, Rawlings & Saunders 1993), to free-free emission from a molecular torus or to the X-ray corona itself (Gallimore et al. 2004). A radiatively inefficient accretion flow accompanied by a relativistic jet has been invoked to explain both the X-ray and radio emission in low luminosity AGN (LLAGN) (e.g., Narayan & Yi 1994, Merloni et al. 2003). Indeed, a correlation between the X-ray and radio luminosity has been found in Panessa et al. (2007) for a sample of local LLAGN, suggesting that either the source of the X-ray and radio emission is the same or that the two emitting components are physically connected. Here we test the validity of such correlations in a sub-sample of relatively high luminosity AGN, as are those detected by the INTEGRAL satellite (e.g., Bird et al. 2010).

2. The samples

The sample is extracted from the third INTEGRAL/IBIS survey which lists around 150 (identified and candidates) AGN (Bird et al. 2007). To this large sample, we have applied the Ve/Va relationship to obtain a complete sample of 88 AGN selected in the hard (20-40 keV) X-ray band above ~ 5 sigma confidence level (see Malizia et al. 2009 for the detailed definition of the sample); the sample includes 46 Seyfert 1 (including 5 Narrow Line objects), 33 Seyfert 2 and 9 blazars. The 20-100 keV and 2-10 keV luminosities used in this work are taken from Malizia et al. (2009). The 1.4 GHz luminosities have been extracted from the NVSS survey (Condon et al. 2008) directly measured from the maps by using the AIPS software. The NVSS images have 45-arcsec full width

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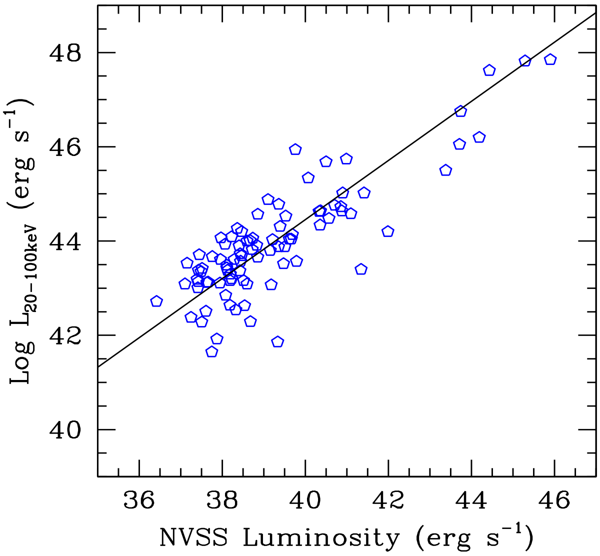

Figure 1: The 20-100 keV luminosity versus the 1.4 GHz NVSS luminosity for the INTEGRAL complete sample together with the best-fit linear regression line.

at half-maximum angular resolution and nearly uniform sensitivity, with a flux density limit of about 2.5 mJy (Maiorano et al. in preparation, Maiorano et al. 2011).

For comparison, we consider a complete distance limited (D $<$ 22 Mpc) sample of LLAGN, as presented in Cappi et al. (2006). It consists of 28 Seyfert galaxies from the Palomar optical spectroscopic survey of nearby galaxies (Ho, Filippenko & Sargent, 1997a, 1997b). The X-ray luminosities are taken from Panessa et al. (2006) and the NVSS ones are from Panessa & Giroletti (in preparation).

3. The X-ray versus radio correlation

In Figure 1, we show the 20-100 keV versus the 1.4 GHz luminosities for the INTEGRAL complete sample, together with the best-fit linear regression line (slope α = 0.6). The hard X-ray luminosity well correlates with the radio emission at tens of arcsecond scales (Pearson correlation coefficient = 0.85). A less tight correlation is obtained if we plot the 2-10 keV luminosity versus the 1.4 GHz luminosity for the same sample, as in Figure 2 (Pearson correlation coefficient = 0.79) and the correlation slope is found to be steeper (α= 0.7). We compared the INTEGRAL complete sample with the optically selected sample of nearby Seyfert galaxies, as shown in Figure 3. At lower luminosity, the best-fit regression line slope is steeper with respect to the best-fit of the INTEGRAL sample (α= 0.9) [1]. This indicates that the extrapolation of the correlation at lower luminosity is not valid for LLAGN, possibly suggesting a different physical origin for the two emissions. However, we must consider that the optically selected sample is limited to the very nearby Universe ($<$ 22 Mpc), while the INTEGRAL sample reaches z = 2.4, although the majority

[1] The survival statistical analysis has been used to take into account for censored data.

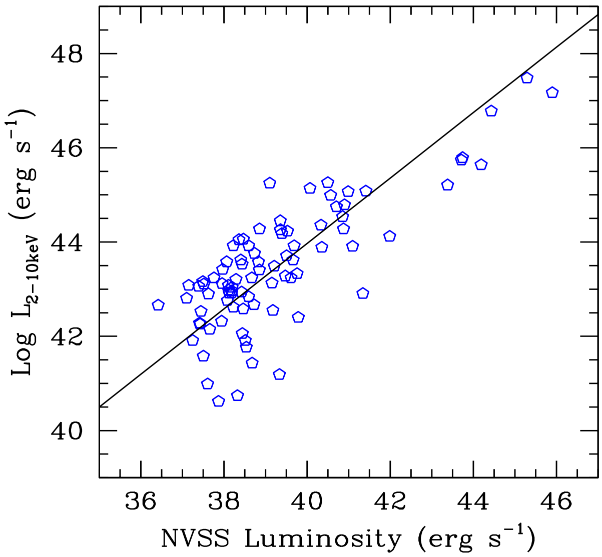

Figure 2: The 2-10 keV luminosity versus the 1.4 GHz NVSS luminosity for the INTEGRAL complete sample together with the best-fit linear regression line.

of the sample sources is concentrated below z = 0.1. A detailed analysis on the distance effects on our correlations will be presented in a forthcoming paper (Panessa et al. in preparation).

4. The X-ray radio loudness parameter in luminous AGN

Terashima & Wilson (2003) have derived the boundary between the radio-loud and radio-quiet objects to be Log R_X = -4.5 (red line in Figure 4). According to the Terashima & Wilson (2003) limit, more than half of the INTEGRAL sample sources should be considered as radio-loud AGN. In Panessa et al. (2007) we have redefined this boundary for LLAGN to be Log R_X=-2.755±0.015 (blue line), according to which the majority of the sample are radio quiet AGN. According to these criteria and to the average radio power (Log $P_{20cm} \sim$ 22-23 W Hz^{-1} sr^{-1}), the sample is mostly made of radio bright AGN but not radio-loud. Indeed, of the 35 type 1 Seyfert galaxies of the sample, only six of them are broad line radio galaxies (see Molina et al. 2007, 2008).

The presence of a strong correlation between the 20-100 keV and 2-10 keV versus the NVSS radio emission in a sample of AGN selected at hard X-rays supports the idea that, even for efficiently accreting AGN, the two physical components are likely connected. However, the fluxes derived using the NVSS data should be taken with caution since they are the total radio flux of the source and may not be representative of the true nuclear radio fluxes. Indeed, at higher spatial resolutions, a large fraction of the radio flux is seemingly resolved (e.g., Giroletti & Panessa 2009, Orienti et al. 2010). The detailed study of the radio properties of the INTEGRAL AGN complete sample is the subject of our ongoing work (Panessa et al. in preparation).

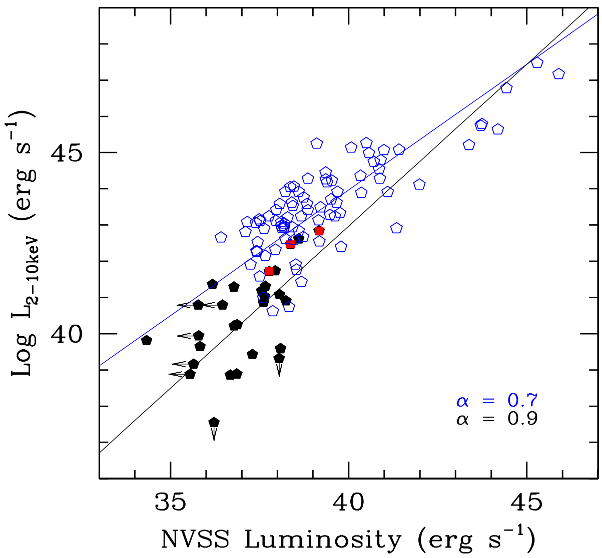

Figure 3: The 2-10 keV luminosity versus the 1.4 GHz NVSS luminosity for the INTEGRAL complete sample (blue symbols) and for the optical complete sample (black symbols). The sources in common between the two samples are marked in red. The best-fit linear regression lines of the two samples are drawn.

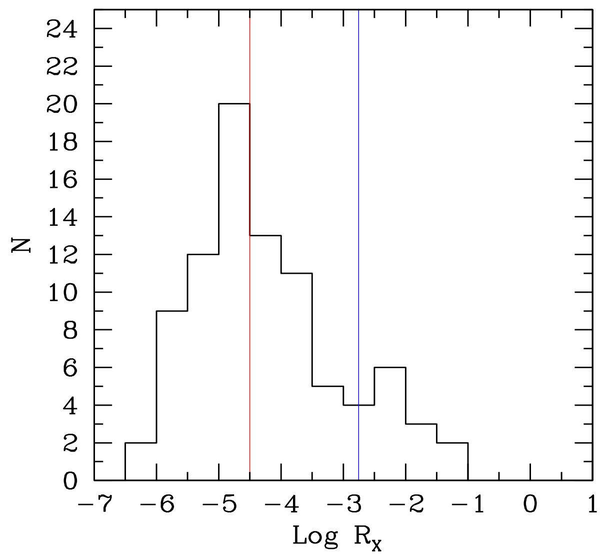

Figure 4: The 2-10 keV versus the 1.4 GHz radio loudness parameter for the INTEGRAL complete sample. The red line is the radio-quiet versus radio loud boundary as in Terashima & Wilson (2003), the blue line is the boundary as redefined in Panessa et al. (2007), see also Sect.4

Acknowledgements
F.P. acknowledges support by INTEGRAL ASI I/033/10/0 and ASI/INAF I/009/10/0.

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