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The X-ray and radio connection in nearby Seyfert galaxies

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Abstract. We present the results on the correlation found between the nuclear 2-10 keV X-ray and radio (at 2 cm, 6 cm and 20 cm) luminosities for a well defined sample of local Seyfert galaxies, suggesting that the accretion flow and the radio source are strongly coupled in these sources. Interestingly, the slope of the correlation is the same found for low luminosity radio galaxies, i.e., objects that are traditionally classified as radio-loud and whose radio emission is ascribed to synchrotron radiation from relativistic electrons. To shed light on the underlying radio physical mechanisms of these radio-quiet sources, we have observed a sub-sample of Seyferts with VLBI high resolution techniques. Indeed, observations of the pc scale and sub-pc scale region of Seyfert nuclei and LLAGN are often successful in the determination of the physical parameters of the nuclear radio components (such as the brightness temperature, the spectral index, the jet motions, etc.). Preliminary results on the EVN radio observations will be here presented and discussed in comparison with multi-wavelength properties and correlations found.

Key words. galaxies: active – galaxies: Seyfert – radio continuum: galaxies

1. Introduction

Sensitive observations reveal that radio-quiet Active Galactic Nuclei (AGN) are not radio silent (e.g. Ho & Ulvestad 2001, Nagar et al. 2002). In this respect, there is growing interest in the understanding of the origin of their radio emission, which is so far poorly constrained. Indeed, several models have been proposed to explain the observed radio properties in the different classes of AGN. For example, compact radio emission from a number of low-luminosity AGN (LLAGN) has been attributed to free-free emission/absorption or advection-dominated accretion flow (ADAF) processes (Gallimore et al. 2004, Ulvestad & Ho 2001); as well as a combination of a compact radio jet with an ADAF (Falcke & Markoff 2000) or a standard accretion thin disk (Ghisellini et al. 2004). In the case of Seyfert galaxies, type 1 nuclei (with an optical broad Hα component) have a significantly higher detection rate than type 2 sources (Nagar et al. 2002), which calls for an accommodation in the unified schemes.

2. The sample

The Seyfert sample studied here has been presented in Panessa et al. (2006). It comprises 47 out of 60 Seyfert galaxies from the Palomar

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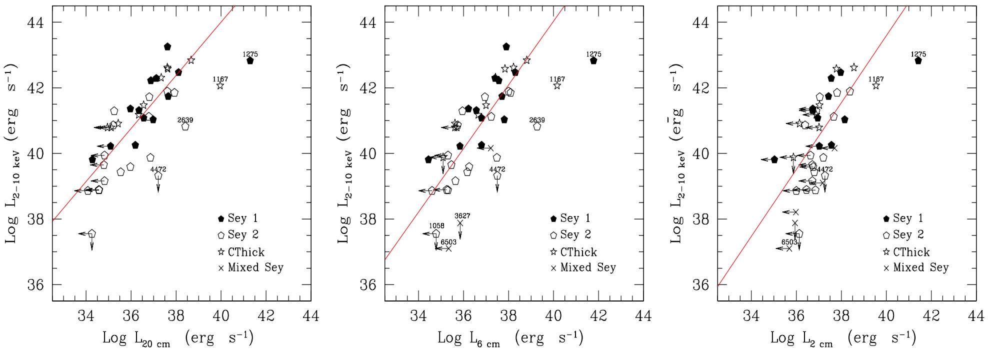

Fig. 1. Intrinsic 2-10 keV luminosity versus core radio luminosity at 20 cm (left), 6 cm (center), and 2 cm (right). Radio data at 20 cm and 6 cm are taken from Ho & Ulvestad (2001), and at 2 cm are from Nagar et al. (2005). Type 1 objects are plotted as filled polygons, type 2 as empty polygons, 'mixed Seyfert' objects as crosses, and Compton thick candidates as stars. The NGC names of a group of radio-loud Seyfert galaxies has been highlighted.

optical spectroscopic survey of nearby galaxies (Ho et al. 1995) for which X-ray data are available. The sources are classified as type 2 (34 out of 60), type 1 (13 out of 60), and "mixed" Seyfert galaxies (8), according to their position in the optical emission line diagnostic diagrams. The "mixed" Seyferts are found near the boundary between Seyfert and LINER, HII or transition classification, resulting in a double classification (e.g., S2/T2, L2/S2, H/S2, etc.). Compton thick candidates have also been identified.

3. The X-ray versus radio correlation

We have studied, for the first time with this sample, the relationship between the X-ray and radio luminosities, combining nuclear X-ray and core radio data obtained in recent surveys (Cappi et al. 2006; Panessa et al. 2006; Ho & Ulvestad 2001; Nagar et al. 2002). As shown in Fig.1, nuclear 2-10 keV X-ray and core radio luminosities at 20 cm, 6 cm, and 2 cm are significantly correlated in these nearby Seyfert galaxies down to very low luminosities ($L_{(2-10 keV)} > 10^{38}$ erg s^{-1}), suggesting a strong coupling between the X-ray and the radio emission mechanisms. The former is commonly ascribed to a disk-corona system and the latter is likely associated with a core jet/outflow.

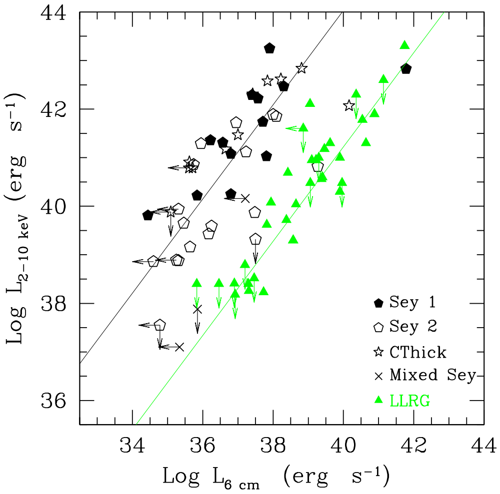

Fig. 2. Intrinsic 2-10 keV luminosity versus core radio luminosity at 6 cm. Seyfert galaxies are plotted as polygons. Low-luminosity radio galaxies are plotted as solid triangles (Balmaverde & Capetti 2006). Seyferts' and LLRGs' best-fit linear regression lines obtained using the Schmitt method have been plotted.

We have selected a sample of low-luminosity radio galaxies (LLRGs) to compare them with the Palomar Seyfert galaxy sample. The LLRGs here selected are taken from two different catalogues (Balmaverde & Capetti 2006; Chiaberge, Capetti & Macchetto 2005). The X-ray versus 6 cm radio luminosity correlations, shown in Fig.2, hold for nearly eight orders of magnitude in both Seyfert and LLRG samples. Interestingly, in the two samples we found a similar correlation slope ($L_X \propto L_R^{0.97}$) suggesting either common physical mechanisms in their nuclei or a combination of different mechanisms that end up producing a similar spectral slope. It has been suggested that the X-ray emission in LLRGs could have a common non-thermal origin as the radio emission, as for example due to synchrotron radiation from a relativistic jet (Balmaverde et al. 2006); however, it is unlikely that this is also valid for Seyfert galaxies, for which a contribution from the accretion-flow/hot-corona system is expected in X-rays.

4. The parsec and sub-parsec scale radio observations

Since nuclear structures in most Seyfert galaxies show very complex morphology, it is of fundamental importance to resolve them with high spatial resolution. Indeed, it has been shown that VLBI observations of the pc and sub-pc region of Seyfert nuclei and LLAGN are often successful in the determination of the physical parameters of the nuclear radio components (such as the brightness temperature, the spectral index, the jet motions, etc.) and therefore in the comprehension of the underlying physical mechanisms. For example, the VLBA study of the classical Seyfert 2 galaxy NGC 1068 has allowed to identify the location of the hidden active nucleus and to attribute the core radio emission to thermal free-free emission from an X-ray heated corona or wind arising from the disk (Gallimore et al. 2004). In the case of the type 1 Seyfert NGC 4151 it has been possible to resolve the 0.2pc two-sided base of a jet whose low speeds indicate non-relativistic jet motions, possibly due to thermal plasma (Ulvestad et al. 2005). On the contrary, the VLBA analysis of the LLAGN NGC 4278 has shown that the radio emission of this source is emitted via synchrotron process by relativistic particles similarly to ordinary radio-loud AGN (Giroletti et al. 2005). These studies indicate that the analysis of individual sources is very important for the determination of the different spatial components and physical parameters.

We are conducting a systematic study of the sub-pc scale properties of a of Seyfert galaxy sample which is well defined and extensively analyzed by our team in different spectral bands. This kind of study is missing so far, notwithstanding its importance to delineate the general properties of Seyfert radio cores on these very small scales and to pinpoint the differences between type 1 and type 2 Seyferts on statistical bases in the framework of Unified Models.

5. The EVN observations

We observed the nuclei of six nearby Seyfert galaxies with the EVN at 1.6 and 5 GHz in May 2007 and Feb 2008. The sources had not been observed before on mas scales, while previous VLA observations have revealed radio cores at a few mJy level at both frequencies, with flat/moderately steep spectral indexes (Ho & Ulvestad 2001). Given the weakness of the sources, we have observed with the phase referencing technique, adopting long exposure times and a large recording rate (1 Gbps). This observing setup results in an rms noise as low as 20 μJy, although some failures affected the observations at 5 GHz which have therefore a higher detection threshold.

In the present work, we only give a preliminary report on the results of the observations. Four sources are clearly detected at at least one frequency: NGC 4051, NGC 4388, NGC 4501, and NGC 5033. Preliminary images of three sources are shown in Fig. 3. The structures are typically unresolved on scales of about 0.1 parsecs, with a flux density of order 1 mJy. Some extended emission could be present in some sources (e.g. NGC 4388, left

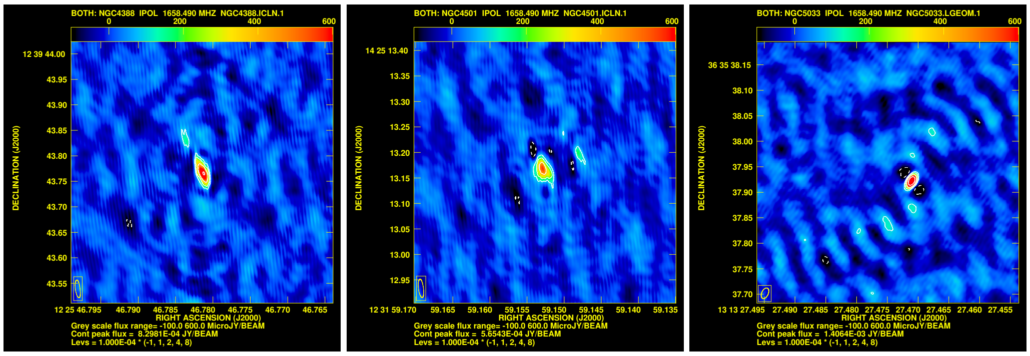

Fig. 3. EVN 1.6 GHz images of NGC 4388, NGC 4501, NGC 5033 (left to right). The lowest contour is traced at 0.1 mJy/beam, and the peak brightness is 0.8, 0.6, and 1.4 mJy/beam, respectively. The restoring beams are shown in the bottom left corner of each image

panel of Fig. 3) but a better analysis is needed to confirm it. The brightness temperatures of the components are typically in excess of 10^8 K, which is suggestive of a non-thermal emission mechanism. Accurate spectral and imaging analysis will be reported in Giroletti & Panessa in preparation.

Our new observations raise the number of sources with compact VLBI features to (at least) 13 out of the 17 sources which are detected by the VLA at 1.6 and 5 GHz. This is suggestive of the fact that nuclear compact radio emission is quite common even in this low luminosity sources.

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