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A Multiband Approach to AGN: Radioscopy & Radio Astronomy

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Abstract. Only in the radio-loud population of active galactic nuclei (AGN) does the production, collimation, and acceleration of powerful relativistic jets take place. We introduce here a concept of combined VLBI- and X-ray spectroscopic observations of sources with relativistic, broad iron lines. This approach has enormous potential to yield deep insights into the accretion/jet-production process in AGN. Better knowledge of the milliarcsecond-resolution radio structure of the nuclear radio cores in so-called "radio-quiet" broad-iron-line Seyfert galaxies is essential for future combined radio/X-ray studies of the different modes of radio-jet production in accreting black hole systems.

Key words. Galaxies: active – Galaxies: Seyferts – Galaxies: jets

1. Introduction

The radioscopic[1] study of relativistically broadened iron lines in the X-ray regime allows the very closest neighbourhood of black holes to be explored: their accretion disks. These are thought to provide the "fuel" for the jet production in radio-loud active galactic nuclei (AGN). It is commonly accepted that broad iron lines arise from fluorescent Kα emission when the accretion disks of AGNs are irradiated by hard X-rays from their coronae. Due to the strong relativistic effects in the inner disk, the iron-line profile is broadened and skewed (e.g., Fabian et al. 2000). If measured precisely enough, it reveals properties of the accretion disk, in particular the orientation, extent and emissivity gradient radially outward from the black hole. Accretion events that might trigger enhanced jet-production activity are expected to cause changes in the line profile. Thus, combined jet and broad-iron-line monitoring can in principle disclose the physical processes in accretion disks that lead to jet production.

While such broad iron lines from radio-quiet AGNs have been extensively studied over the last decade, no significantly broad-

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[1] radioscopy: examination of the inner structure of opaque objects using X rays or other penetrating radiation (WordNet 2.0, http://www.cogsci.princeton.edu/~wn)

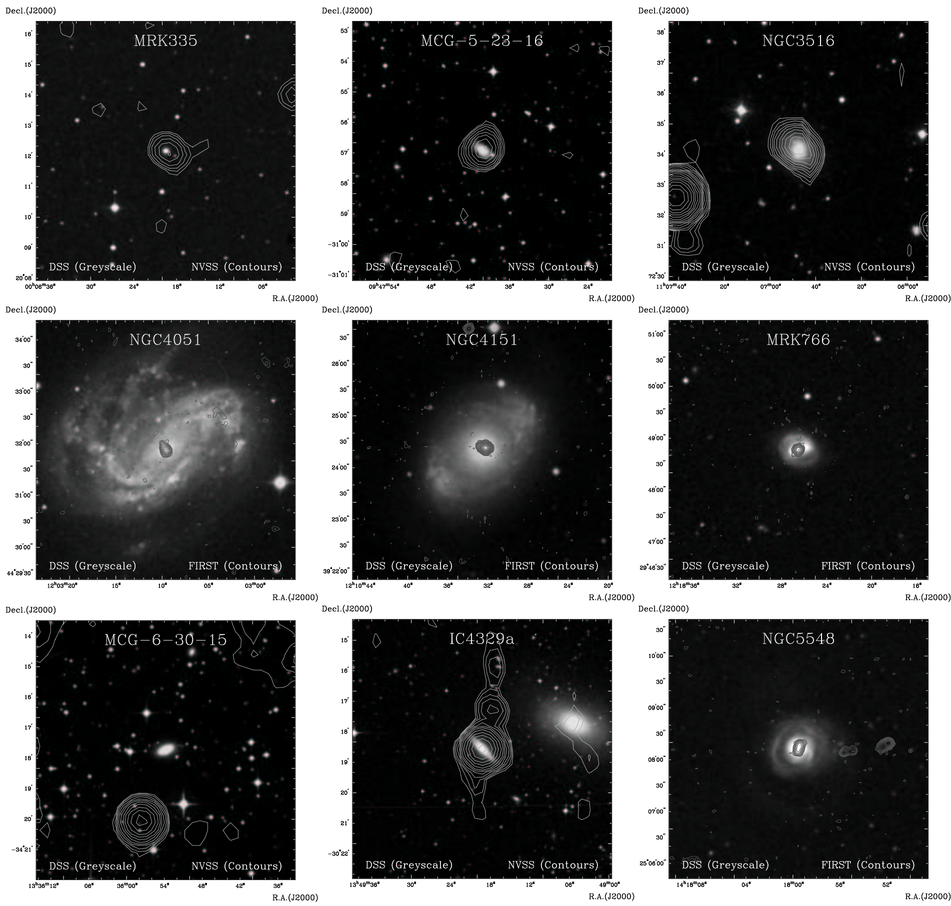

Fig. 1. Compact radio cores in "radio-quiet" Seyfert galaxies. Images display the optical host galaxies (DSS2 data), while contours show the radio structure at 1.4 GHz (FIRST and NVSS data, respectively). Integrated flux densities at $\lambda 6$ cm are given in Table 1.

ened lines have been detected in the X-ray spectra of radio-loud AGN (Sambruna et al. 1999, Gambill et al. 2003), which has been explained by either dominant beamed jet components, very high ionization of the disks, or optically-thin, radiatively-inefficient accretion flows. Contrary to this expectation, the first highly relativistic, broad iron line in a radio-loud AGN was detected in NGC 1052 (Kadler et al. 2004). Not only is there a broad line, but a change in the line profile coincides with an epoch of jet-plasma ejection.

At present NGC 1052 is the only strong radio source known for which straightforward observational input can be gained from combined high-resolution Very-Long-Baseline Interferometric (VLBI) observations and X-ray iron-line monitoring. Thus, it is worthwhile to review the known radio-core properties of the so-called "radio-quiet" broad-iron-line Seyfert galaxies. We show here that these sources are not so quiet after all at radio wavelengths but comprise a sample suitable for coordinated X-ray and VLBI monitoring.

2. The Compact Radio Cores in Broad-Iron-Line Seyfert Galaxies

After the first detection of an extragalactic broad iron line associated with the Seyfert

Table 1. The sample

Source	$S_{6\text{cm}}^{\text{VLA}}$ [mJy]	$F_{(2-10)\,\text{keV}}$ [erg cm^{-2} s^{-1}/10^{11}]	Broad Iron Line	Notes
Mrk 335	4.3[a]	1.7[b]	Yes[c]	Seyfert 1. Steep X-ray continuum with photon index of ~2.3[(c)]. Line profile might indicate a highly ionized, innermost region of the accretion disk around a rotating black hole.
MCG −5−23−16[d]	6.0[a]	7.5[e]	Yes[e]	Seyfert 1.9. Broad iron line emission, variable on timescales of months[e]. Time stable narrow fine-scale features. VLBI-unobserved.
NGC 3516	4.3[a]	5.0[b]	Yes[f]	Narrow fine scale features indicate injection of material with a speed of 0.25 *c*[f].
NGC 4051	6.0[a]	2.0[b]	Disputed[g,h]	X-ray and radio variability[i]. Correlation between the (accretion dynamics dominated) X-ray flux and the (jet dominated) radio flux.
NGC 4151	125.0[a]	0.2[b]	Disputed[j]	*XMM-Newton* spectrum does not require a relativistically broadened iron line. Narrow and variable Fe line, with amplitude of ~25%. Compact jet[k,l]
Mrk 766	15.8[m]	1.9[b]	Yes[n]	Broadened iron emission lines at 6.4 keV and 6.7 keV. Unconfirmed highly relativistic "red wing"[n]. Blueshifted Fe absorption edge at 8.7 keV, suggesting ejected material at speeds of 15,000 km s^{-1} ($\beta \sim$ 0.05). Only barely resolved with VLBI[o]
MCG −6−30−15	1.0[a]	3.8[b]	Yes[p]	The archetypical broad-iron-line galaxy. Broad and variable profile, fine structure[q]. Compact VLA structure. VLBI-unobserved.
IC 4329a	31.5[m]	8.3[b]	Disputed[r]	Disk possibly truncated shortly before reaching the innermost stable orbit around the central black hole[s]. VLBI-unobserved.
NGC 5548	10.5[m]	6.0[t]	Disputed[t]	Soft excess varies more strongly than the high-energy continuum[u]. The spectrum shows reflection and fluorescence from neutral iron distant from the central source[t]. Rapid radio variability[v].

[a] Ulvestad & Wilson 1984; [b] HEASARC website: `http://heasarc.gsfc.nasa.gov/`; [c] Gondoin et al. 2002; [d] See Fabian et al. 2000 for a review; [e] Dewangan et al. 2003; [f] Turner et al. 2002; [g] Wang et al. 1999; [h] Pounds et al. 2004; [i] McHardy et al. (2004, & priv. comm.); [j] Schurch et al. 2003; [k] Ulvestad et al. 1998; [l] Mundell et al. 2003; [m] Rush et al. 1996; [n] Pounds et al. 2003b; [o] Lal et al. 2004; [p] Fabian et al. 2002; [q] Wang et al. 2004; [r] Gondoin et al. 2001; [s] Done et al. 2000; [t] Pounds et al. 2003a; [u] Done et al. 1995; [v] Wrobel 2000

galaxy MCG −6−30−15 (Tanaka et al. 1995) there followed a boom of follow-up *ASCA* detections in other Seyfert galaxies and relativistic iron lines seemed to become a common ingredient of Seyfert X-ray spectra. However, in several cases *XMM-Newton* could not verify the broad, relativistic red wings. Firm *XMM-Newton* detections of broad iron lines have been reported only for MCG −6−30−15, MCG −5−23−16, NGC 3516, Mrk 335, and Mrk 766 (see Table 1 for references). It is not clear at present, whether insufficient data quality from *ASCA* and over-simplified spectral models have led to the discrepancy between the apparent presence of broad lines in IC 4329a, NGC 4051, NGC 4151, and NGC 5548 or if intrinsic line variability in these sources might have played a crucial role. In Fig. 1 we show the arcsecond-scale radio structure[2] of those Seyfert galaxies superimposed on optical images from the Digitized Sky Survey[3] compiled by using *Sky View*[4]. All sources in this sample harbour compact radio cores at their centres. Only in the case of MCG −6−30−15 does the flux density lie below the detection limit of the NVSS. Several authors, however, report the detection of a weak but possibly highly variable flat-spectrum radio core in MCG −6−30−15, e.g., Ulvestad & Wilson (1984) report 1.7 mJy at λ20 cm whilst Nagar et al. (1999) measure 4.0 mJy.

[2] Where available, we used radio images from the FIRST survey (`http://sundog.stsci.edu`), otherwise we used images from the NVSS (`http://www.cv.nrao.edu/nvss`)

[3] The Digitized Sky Survey was produced at the Space Telescope Science Institute under U.S. Government grant NAG W-2166. The images of these surveys are based on photographic data obtained using the Oschin Schmidt Telescope on Palomar Mountain and the UK Schmidt Telescope. The plates were processed into the present compressed digital form with the permission of these institutions.

[4] `http://skyview.gsfc.nasa.gov`

3. Multiband-Scrutiny of Broad-Iron-Line Galaxies

Combined VLBI (radio astronomical) and X-ray spectral (radioscopic) observations of AGN that exhibit both a strong broad iron line and a compact radio jet can study the coupling of mass accretion and jet formation around supermassive black holes. Processes that trigger jet production are expected to leave clear marks in the time-dependent relativistic-iron-line profile, which is sensitive to changes of the inner edge of the accretion disk and so is possibly the most direct tracer of dynamical processes in the accretion flow. More complicated models might invoke changes in the structure of the magnetic field in and above the disk. According to these models, turbulent field corresponds to higher disk viscosity while predominantly poloidal field facilitates flow of energy into the jet (e.g., Livio et al. 2003). Tagger et al. (2004) propose that there is a period of mainly poloidal field during which the accretion flow moves toward smaller radii until it reaches the innermost orbit. At this point reconnection of the field lines can inject energy into the jet explosively (Eikenberry & van Putten 2003). Alternatively, instabilities in the inner disk could cause the accretion flow to be irregular (Belloni 2001), with ejection of extra material into the jet occurring when a chunk of matter suddenly falls inward. Such scenarios are under active development to build models that will predict the variation of the iron line profile together with that of the X-ray continuum. We are beginning combined VLBI and X-ray monitoring observations of these broad-iron-line AGN to yield the data needed to test such models.

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