ACCESSING THE INNERMOST REGIONS
OF ACTIVE GALACTIC NUCLEI

E. Ros
Max-Planck-Institut für Radioastronomie, Bonn, GERMANY

M. Kadler
Max-Planck-Institut für Radioastronomie, Bonn, GERMANY and
NASA/Goddard Flight Space Center, Greenbelt, MD, USA

Abstract: Very-long-baseline interferometry can image the parsec-scale structure of radio jets, but the accretion disk close to the black hole remains invisible. One way to probe this accretion flow is provided by X-ray flux density monitoring and spectroscopy. Here we report on preliminary results of a multi-band campaign on NGC 1052 with the goal of combining both approaches to access to the innermost regions of this active galaxy and to establish a connection between the relativistic jets and the accretion region.

Introduction  Active galactic nuclei (AGN) can be studied throughout the electromagnetic spectrum. Over decades, the structure of their jets at parsec scales has been studied via very-long-baseline interferometry (VLBI). Detailed X-ray monitoring has become possible in the last years with satellites like RXTE, XMM-Newton, and Chandra and has yielded not only images at kiloparsec scales, but also spectra and brightness variability on short time-scales. The relativistic Fe Kα line at $\sim 6.4$ keV probes directly the accretion flows (usually found in Seyfert 1 galaxies; Nandra et al. [1997]). This feature had not been observed in AGN until recently.

An extensive study of AGN is being performed at radio frequencies since the mid 1990s, namely the VLBA$^3$ 2 cm Survey (see Zensus et al. [2002] and Kellermann et al. [2004])), continued as MOJAVE since 2002 (see Lister & Homan [2005]). This observational effort consists of the monitoring of up to 200 sources to determine the kinematics of their milliarcsec-scale jet systems. A sub-sample has been studied at X-ray wavelengths by Kadler [2005] with

---

$^1$ER has been partly supported by Grant AYA2005-08561-C03-03 of the Spanish DGI-CYT to attend this conference.

$^2$MK has been supported by the International Max Planck Research School for Radio and Infrared Astronomy at the Universities of Bonn and Cologne and by a NASA Postdoctoral Program Fellowship appointment conducted at the Goddard Space Flight Center.

$^3$The Very Long Baseline Array is operated by the National Radio Astronomy Observatory, a facility of the USA National Science Foundation operated under cooperative agreement by Associated Universities, Inc.
Facility  | Obs. type                      | Comments                                               
----------|-------------------------------|-------------------------------------------------------- 
RXTE      | 2–10 keV monitoring           | 30 epochs of 2 ks each, scheduled every three weeks    
Chandra   | Imaging/Spectroscopy          | One deep obs. in September 2005                        
XMM-Newton| Imaging/Spectroscopy          | One triggered obs. in Feb 2006                         
Effelsberg| $\lambda\lambda 13/6/3.6/2.8/2.13/\sim 70$ h obs. scheduled every three weeks 
| 0.9 cm light curve               |                                                        
UMRAO &  | $\lambda\lambda 31/13/7.7/6/3.9/3.6$/Observations inserted in long-term programs  
RATAN-600 | 2.7/2/1.4 cm light curve      |                                                        
VLBA      | $\lambda\lambda 7/13$ mm imaging | 18 epochs of 6 h each scheduled every six weeks         

Table 1: Multi-mission campaign on NGC 1052

the aim of comparing different physical properties of the central regions and of the extended jets and eventually to connect the phenomena observed in the radio jets with the accretion disk changes seen at X-ray wavelengths. The majority of radio-loud, core-dominated AGN is well described by a one- or two-component power law, with photon indices typically around 1.6 to 1.7. A small subset exhibits additional X-ray spectral features that allow probing the inner accretion flow.

Multi-band observations of NGC 1052  The radio loud, core-dominated active galaxy NGC 1052 ($z=0.0049$) has provided key results in the context mentioned above. This source has been monitored for more than a decade as part of the VLBA 2 cm survey/MOJAVE projects. Multiple sub-parsec scale features display outward motions of $0.26c$ in the jet and the counter-jet (e.g. Vermeulen et al. [2003]). At X-ray wavelengths, the source presents an unusually flat spectrum with a soft excess (e.g. Weaver et al. [1999], Kadler et al. [2004]). Kadler [2005] reported a relativistic broad iron line in NGC 1052, the first such feature found in a radio-loud AGN. The line profile discloses the disk nature and shows variability from epoch 2000.03 to 2001.62. A major jet-production event took place around the same time.

We have set up a radio/X-ray monitoring of NGC 1052\(^4\) to trace the ejecton of new components right from the jet base along both sides of the jet system with the VLBA, together with X-ray monitoring with RXTE to probe the variability and spectrum of the accretion disk and eventually establish correlations and cause-effect relationships. The campaign is described in Table 1. First results are described here.

The results from the RXTE light curve show that the historically well

\(^4\)The NGC 1052 campaign is carried out in collaboration with J.A. Zensus, E. Angelakis, K.A. Weaver, J. Kerp, S. Kaufmann, A.P. Marscher, H.D. Aller, M.H. Aller, J.I. Irwin, and Y.Y. Kovalev.
Figure 1: The varying radio structure of NGC 1052 at sub-parsec scales during our monitoring program. The images are shown spaced by their relative time intervals. The common restoring beams are 0.8×0.4 mas$^2$ and 0.5×0.25 mas$^2$, respectively (both at P.A. 0°). The images have been aligned arbitrarily to the gap between jet and counter-jet (left column) and at the brightness peak (right column). A detailed phase-referencing analysis is pending.
known “unusually flat X-ray spectrum” of NGC 1052 is seen only in individual epochs. At other times, the spectrum is steeper and Seyfert like.

The source was in a relatively bright radio state through 2005 and exhibited several local maxima, corresponding to ejections of new components into the jet and counter-jet system. VLBI imaging results at 7 mm and 13 mm wavelengths are presented in Fig. 1. The images at 7 mm show the emission in the region between the jet and counter jet which, at 13 mm is a gap free of emission due to free-free absorption. A detailed model fit analysis to parametrize the kinematics and the changing flux densities in the image features is pending, as well as the proper astrometric registration of the images from a phase-referencing analysis.

**Summary and Prospects** The combination of radio and X-ray observations of NGC 1052 addresses the question of the radio loudness of AGN and its connection with jet physics. In this context, NGC 1052 is a key source for jet/disk connection studies, since it is favorably observed at both frequency ranges. In general this connection can be established by studying the X-ray variability on weekly time-scales, relativistic iron line changes, and the ejection of new VLBI components.

Looking to the future, the telescopes for the next decade will make possible similar detailed studies in many sources. The Square Kilometre Array era will open the avenue to radio studies of active galaxies in the radio-quiet regime (e.g., Seyfert galaxies with broadened iron lines), and Constellation-X (see White et al. [2004]) will complement the SKA in the X-ray band. It will provide enough sensitivity to probe the accretion disk changes in almost real time in prominent broad-iron-line systems and will disclose many other radio-loud AGN with broad iron lines that are dulted by the underlying power-law continuum.

**References**

[2005] Kadler, M. 2005, PhD Thesis, Univ. Bonn  
[2004] Kadler, M., et al. 2004, A&A, 420, 467  
[2004] Kellermann, K. I., et al. 1998, ApJ, 609, 539  
[2005] Lister, M. L. & Homan, D. C. 2005, AJ, 130 ,1389  
[1997] Nandra, K. 1997 ApJ, 477, 602  
[2003] Vermeulen, R.C., et al. 2003, A&A, 401, 113  
[1999] Weaver, K. A., et al. 1999, ApJ, 520, 130  
[2004] White, N. E., et al. 2004, Proc. SPIE, 5488, 382  
[2002] Zensus, J. A., et al. 2002, AJ, 124, 662