PROCEEDINGS OF SCIENCE

Kinematics of Relativistic AGN Jets

M. L. Lister*
Purdue University, USA
E-mail: `mlister@purdue.edu`

Since 1994 we have been carrying out a long term campaign to study the milliarcsecond-scale relativistic jet structure and kinematics in a large sample of over two hundred active galactic nuclei (AGN) with the VLBA at 15 GHz (the VLBA 2cm Survey and MOJAVE: Monitoring Of Jets in Active galactic nuclei with VLBA Experiments). This represents one of the largest and most complete AGN jet studies to date, and comprises several thousand individual VLBA images spanning more than a decade of jet evolution. Our kinematic analysis of over 500 distinct features in the jets of 135 core-selected AGN has revealed that only $\sim$ 1/4 of the features are moving outward from the base of the jet at constant velocity in a purely radial direction. The majority of features are travelling outward on accelerating (non-ballistic) trajectories at apparent superluminal speeds ranging up to 50 c. The statistics from the MOJAVE survey are being used to study the variety of complex fluid instabilities that are likely present in these relativistic outflows.

The 9th European VLBI Network Symposium on The role of VLBI in the Golden Age for Radio Astronomy and EVN Users Meeting
September 23-26, 2008
Bologna, Italy

*The author wishes to acknowledge the contributions of the following MOJAVE team members: H. Aller, M. Aller, M. Cohen, D. Homan, M. Kadler, K. Kellermann, A. Pushkarev, E. Ros, T. Savolainen, R. Vermeulen, & A. Zensus.

PoS(IX EVN Symposium)082

The study of structural evolution of relativistic jets in active galactic nuclei with VLBI has provided us with invaluable data on how these outflows are accelerated and collimated on parsec scales. The VLBA has played a central role in these studies, by providing high-quality images of AGN jets with regular temporal sampling. One of the largest and most comprehensive VLBI studies to date is the MOJAVE program [4, 5], which began in 2002 as a full-polarization extension to the VLBA 2 cm survey that covered the years 1994–2002 [2, 3, 7].

The main goals of the MOJAVE program are to investigate the kinematic properties of a well-defined sample of jets, in order to better understand the physics of jet collimation, how structural changes are related to polarimetric properties and high-energy flaring behavior, and the overall distribution of speeds in the general AGN jet population. The latter is vital for deconvolving the complex selection effects that are found in AGN samples selected on the basis of beamed jet emission (i.e., blazars).

For our program we constructed a flux-density limited sample of compact northern AGN, which consisted of all the brightest extragalactic radio jets as seen by the VLBA at 15 GHz. A total of 135 AGN were sufficiently bright to meet the VLBA flux density criteria (1.5 Jy for $\delta > 0^\circ$, and 2 Jy for $-20 < \delta < 0^\circ$) on at least one occasion during the years 1994.0-2004.0. These sources, along with approximately 70 other AGN of particular interest, are being observed in full polarization at regular intervals with the VLBA in support of the Fermi gamma-ray observatory, whose source catalog is expected to be dominated by compact radio-loud blazars. More details of our VLBA observations, as well as archival and recently obtained data, can be found on our project webpage[1].

1. Jet Kinematics

We have recently completed an analysis of over 2400 individual VLBA images of the MOJAVE flux-density limited sample, obtained as part of our program and the NRAO archive. The temporal coverage per source ranged from 5 to 89 epochs, with a median of 15 epochs, and spanned the time range between Aug. 1994 and Sept. 2007. Attempts were made to sample the more rapidly evolving sources more frequently in time, so as to not undersample their kinematic evolution. An example of a well-sampled source (3C 273) is shown in Figure 1, which shows the separation distance versus time of individual jet features from the (presumed stationary) optically thick core component located near the base of the jet. Since many of the components follow curved trajectories, we have fit both linear and accelerating models to the positions of the features on the sky[1]. An analysis of over 500 individual features in our sample indicates that accelerated motions are very common, with only 27% of the features having motions that are consistent with simple constant-speed ballistic trajectories in the purely radial direction. Curved trajectories have been detected previously in several individual jets such as 3C 273, and have been suggested to result from helical Kelvin-Helmholtz instabilities in the flow[6]. The underlying driver for these instabilities is still not well known. The MOJAVE program is currently providing important statistical data for testing these and other models of jet bending.

The author wishes to acknowledge grant support for the MOJAVE program provided by the NSF (0807860-AST) and NASA (NNX08AV67G).

[1] www.physics.purdue.edu/MOJAVE

PoS(IX EVN Symposium)082

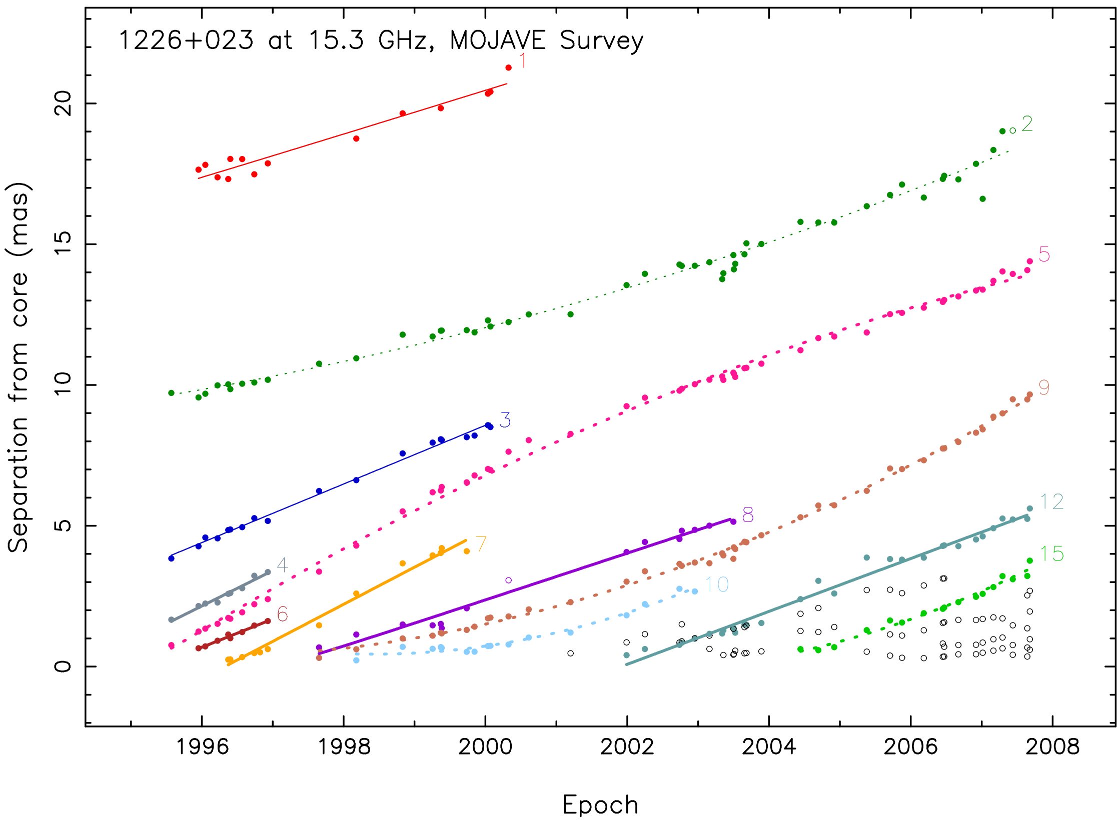

Figure 1: Plot of angular separation from core versus epoch for Gaussian components in the jet of 3C 273. Color symbols indicate components for which kinematic fits were obtained. The solid lines indicate vector motion fits assuming no acceleration, while the dotted lines indicate accelerated motion fits. Thick lines indicate that the best-fit motion is along a radial direction from the core, while the thin lines indicate non-radial motions. Unfilled color symbols indicate individual data points that were not used in the kinematic fits. Components that could not be reliably identified across the epochs are plotted as unfilled black circles.

References

[1] D. C. Homan, et al., *Parsec-Scale Blazar Monitoring: Proper Motions*, *ApJ*, 549, (2001), 840-861

[2] K. I. Kellermann, R. C. Vermeulen, J. A. Zensus, & M. H. Cohen, *Sub-Milliarcsecond Imaging of Quasars and Active Galactic Nuclei*, *AJ*, 115, (1998), 1295-1318

[3] K. I. Kellermann, et al., *Sub-Milliarcsecond Imaging of Quasars and Active Galactic Nuclei. III. Kinematics*, *AJ*, 609, (2004) , 539-563

[4] M. L. Lister, & D. C. Homan, *MOJAVE: Monitoring of Jets in Active Galactic Nuclei with VLBA Experiments. I. First-Epoch 15 GHz Linear Polarization Images*, *AJ*,130, (2005), 1389-1417

[5] M. L. Lister, et al., *MOJAVE: Monitoring of Jets in AGN with VLBA Experiments. V. Multi-epoch VLBA Images*, *AJ*, submitted (2009)

[6] Perucho, M., Lobanov, A. P., Martí, J.-M., & Hardee, P. E., *The role of Kelvin-Helmholtz instability in the internal structure of relativistic outflows. The case of the jet in 3C 273*, *A&A*, 456, (2006), 493-504

[7] J. A. Zensus, E. Ros, K. I. Kellermann, M. H. Cohen, R. C. Vermeulen, & M. Kadler, *Sub-Milliarcsecond Imaging of Quasars and Active Galactic Nuclei. II. Additional Sources*, *AJ*, 124 (2002), 662-674