VLBI IMAGING OF THE X-RAY BRIGHT LOBE HOTSPOT IN PKS B2152−699

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Abstract

Wide-field very long baseline interferometric (VLBI) imaging can be used to study the compact radio structures in extended extragalactic radio sources such as starburst galaxies and radio galaxies. Recently, compact radio emission has been detected from the southern lobe hotspot in the nearby, powerful radio galaxy PKS B2152−699, using an array of Southern Hemisphere radio telescopes, resulting in the highest spatial resolution image of a radio galaxy hotspot to date. These VLBI data are being analyzed in conjunction with *HST* optical and *Chandra* X-ray observations to give a complete picture of the relationship between the relativistic jet in PKS B2152-699 and the host galaxy environment.

1 Introduction

PKS B2152−699 is a relatively powerful, nearby (z = 0.0282) radio galaxy (Tadhunter et al., 1988); it is one of the brightest radio sources in the sky at 2.3 GHz (Wall, 1994) and was identified optically by Westerlund & Smith (1966).

PKS B2152−699 was the first astronomical target of the Australia Telescope Compact Array (ATCA) (Norris et al., 1990). Subsequent large-scale radio imaging by Fosbury et al. (1990), Jones & McAdam (1992), and Fosbury et al. (1998) show that PKS B2152−699 has a double-lobed structure with prominent lobe hotspots and a bright nuclear radio source. The radio source is oriented approximately north-south and has a total extent of approximately 120 kpc. Approximately 10″ north of the nuclear radio source (a quarter of the way to the northern lobe hotspot) there is a bright radio hotspot. Ground-based (Tadhunter et al., 1987, 1988) and *HST* (Fosbury et al., 1998) optical imaging shows that this hotspot is coincident with a highly ionized cloud of gas. Also apparent is a misalignment between the nucleus-cloud position angle and the position angle connecting the nucleus and the northern lobe hotspot (approximately 20°). Although early radio imaging did not detect the radio jets in PKS B2152−699, Tadhunter et al. (1988) suggested that the coincidence between the highly ionized cloud and the radio hotspot could be explained by an interaction between a relativistic jet originating at the nucleus and a cloud of gas in the host galaxy. Tadhunter et al. (1988) explain the $\sim 20°$ misalignment as due to the deflection of the relativistic jet in the interaction.

Very long baseline interferometry (VLBI) observations by Tingay et al. (1996) directly detected the parsec-scale jet at the nucleus of PKS B2152−699 and showed that it was highly aligned with the cloud/hotspot complex, not the northern radio lobe hotspot, strengthening the evidence for a jet/cloud interaction. Tingay et al. (1996) also quantified the idea of a jet deflection using a simple model of oblique shocks in a relativistic jet (Tingay, 1997), showing that a $\sim 20°$ deflection was plausible. Fosbury et al. (1998) presented a summary of the highest resolution radio and optical data available, showing the detailed relationship between the parsec-scale radio jet and the large-scale radio and optical structures.

Very recently, *Chandra* X-ray observations of PKS B2152−699 have been made, detecting significant X-ray emission from the nucleus, jet/cloud interaction region, and both northern and southern radio lobe hotspots. These *Chandra* data, new wide-field VLBI data, and archival *HST* optical data are currently being prepared for publication by Andy Young, Andrew Wilson, and Steven Tingay. The aim of this paper in preparation is to examine the X-ray emission mechanisms operating in PKS B2152−699 and to investigate further the energetics of the jet/cloud interaction.

In this brief proceedings paper I will outline the wide-field VLBI observations that have been undertaken and refer the reader to the above mentioned paper for full details of the analysis and interpretation of the PKS B2152−699 multi-wavelength data.

2 Wide-field VLBI observations of PKS B2152−699

PKS B2152−699 was observed with three elements of the Australian Long Baseline Array (LBA) on 2003 February 15, over a period of 6 hr at a frequency of 1400 MHz, using a total bandwidth of 32 MHz (dual polarization 16 MHz bands). The observations were correlated (using the bright nuclear source as the phase-tracking center) on the LBA S2 correlator at ATNF headquarters in Epping and the correlated output was exported to AIPS[1] for initial processing. The data were correlated using a 2 second integration period and 0.25 MHz channels to allow an imaging field of view that would allow access to the entire angular extent of the radio galaxy.

The data were fringe-fitted and amplitude calibrated in AIPS then the data were exported to DIFMAP (Shepherd, Pearson & Taylor, 1994) for initial imaging. The data were vector averaged over the full bandwidth and a 30 second timescale, then imaged using standard self-calibration techniques. An image of the nuclear radio source was produced in this way (Young, Wilson & Tingay, 2004) which is completely consistent with the image presented by Tingay et al. (1996). The phase self-calibration corrections derived from this procedure were then applied to the unaveraged dataset and the data were exported to the MIRIAD package (Sault, Teuben & Wright, 1995) for further imaging. InMIRIAD the data were edited (recalculation of the *u, v, w* coordinates) to allow images to be made at three additional phase centers: the northern lobe hotspot; the southern lobe hotspot; and the jet/cloud interaction region. The images of these regions were then made simply by using the deconvolution routines in MIRIAD.

[1]The Astronomical Image Processing Software (AIPS) has been developed and is maintained by the National Radio Astronomy Observatory, which is operated by Associated Universities, Inc., under cooperative agreement with the National Science Foundation

3 Compact radio emission from the southern lobe hotspot

The images made of the three extra-nuclear regions had a 3σ detection limit of approximately 3 mJy beam^{-1}. No significant emission was detected from the northern lobe hotspot or the jet/cloud interaction region. However, a relatively bright and compact radio source was detected and imaged at the location of the southern lobe hotspot (Young, Wilson & Tingay, 2004). The maximum angular resolution achieved in this image was 90 mas, meaning that this image is the highest spatial resolution image ever made of a radio galaxy lobe hotspot. Previously, the Perley, Röser & Meisenheimer (1997) Very Large Array (VLA) images of the western hotspot in Pictor A at a wavelength of 2 cm (angular resolution also 90 mas) were the highest spatial resolution images of a radio galaxy hotspot. Since PKS B2152−699 is approximately 20% closer than Pictor A, the new 20 cm VLBI images of PKS B2152−699 are of a slightly higher spatial resolution than the VLA 2 cm images of Pictor A.

The VLBI image of the southern lobe hotspot shows three separate components spread over an angular region of approximately 500 mas in diameter, plus a small amount of diffuse emission. The total flux density of the compact emission from the southern lobe hotspot is approximately 0.1 Jy, with the brightest of the three components having a total flux density of approximately 65 mJy. The peak flux density in the image is approximately 17 mJy beam^{-1}.

4 Concluding comments

Reasonably sensitive, high resolution, wide-field VLBI observations are now possible using the Australian LBA. Wide-field techniques for VLBI have been championed in recent years by Mike Garrett and collaborators, mainly in Europe. A number of recent results have shown the utility of this technique and the work on PKS B2152−699 briefly described here, and the work on the starburst galaxy NGC253 (Tingay, 2004), show that the Australian LBA is a useful instrument for wide-field VLBI.

The southern lobe hotspot in PKS B2152−99, detected using wide-field techniques, is also strongly seen in X-ray emission. Young, Wilson & Tingay (2004) are currently examining a number of possibilities for the X-ray emission mechanism in the lobe hotspots of PKS B2152−699, based on these VLBI data and *Chandra* X-ray data. From the same data sets, as well as archival *HST* data, Young, Wilson & Tingay (2004) are also examining the energy budget in the jet/cloud interaction region of PKS B2152−699.

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