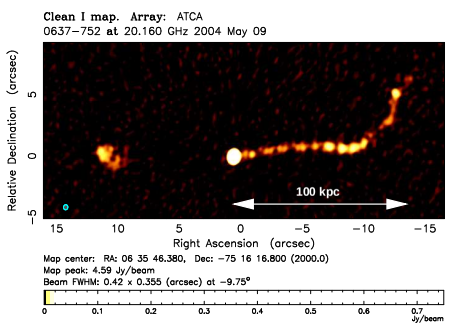
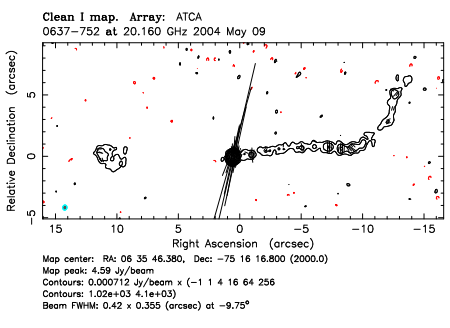
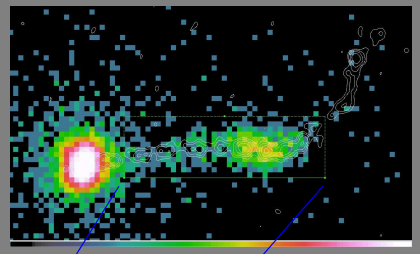
The kpc−Scale Jets of PKS 0637−752 and PKS 2101−490 As Seen With Chandra and The Australia Telescope Compact Array

Leith Godfrey (ANU − lgodfrey@mso.anu.edu.au), Jim Lovell (ATNF/CSIRO), Geoff Bicknell (ANU), Dan Schwartz (SAO), Jonathan Gelbord (MIT)
Dave Jauncey (ATNF/CSIRO), Herman Marshall (MIT), Diana Worrall, Mark Birkinshaw (Bristol Uni.)
Eric Perlman, Markos Georganopoulos (UMBC),Sebastian Jester (Fermilab), David Murphy (JPL)





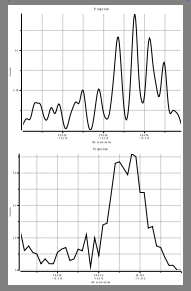


Above Left: 20.16GHz ATCA image of PKS 0637-752
Left: Chandra X-ray raw counts (0.5 - 7.0 keV) image of PKS 0637-752 with 20.16GHz contours overlaid. Pixel size is 0.246 arcseconds. Purple corresponds to one count per pixel. The peak counts per pixel in the jet is 18, displayed as orange.

Above Right: Contour representation of image to left, showing polarization E-vectors. Length of vectors is proportional to polarized flux density with 0.4 arcseconds per m Jy. Assuming negligible rotation measure, the direction of the E-vectors is perpendicular to the magnetic field direction in the plane of the sky.

Introduction

Here we present initial results of a multi-wavelength observing program aimed at studying the dynamics of large scale X-ray bright quasar jets. The recent millimetre upgrade to the Australia Telescope Compact Array (ATCA) has provided imaging capabilities with much higher resolution (approximately 0.5 arcseconds) than was previously possible for these southern quasar jet sources. The new radio images reveal much greater detail, and a number of intriguing jet features. These radio images will be combined with radio imaging at longer (cm) wavelengths, as well as X-ray (Chandra) and optical imaging (HST data are in hand) to study the evolution of, and relation between the various emission properties along the jets, and in turn, model the plasma properties and flow of the jet.

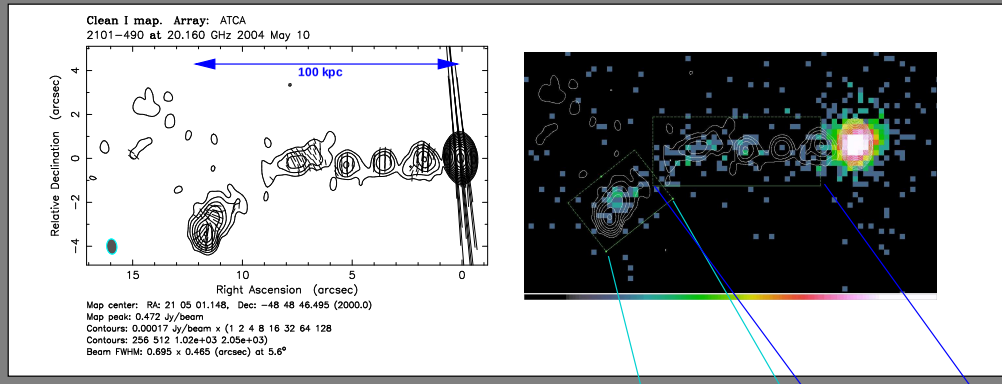


Above: Jet profiles along regions shown on X-ray image above.

PKS 0637-752

- Flat spectrum radio quasar at z=0.654
- VLBI observations of pc-scale jet imply angle to line of sight $\sim 6^{o}$ (Lovell et al. 2000) => X-ray jet has deprojected length of $\sim$ 940 kpc.
- X-ray Emission
  - Continuous inner jet, starting at around 3 arcseconds from the core, peaking between 7.5 to 9.5 arcseconds from the core, then terminating at, or shortly after the bend in the radio jet at apprximately 10 arcseconds from the core.
- Radio Emission
  - The new ATCA images reveal a highly knotted structure, with gentle curvature of the inner jet preceding a rapid change in direction at about 10 arcseconds from the core.
  - Three of the inner jet knots (between 2 to 6 arcseconds from the core) exhibit a paired structure, with peak offsets of $\sim$ 0.3 - 0.4 arcseconds $\sim$ 23 - 30 kpc deprojected.
  - The region of peak X-ray emission between 7.5 to 9.5 arcseconds from the core is resolved into four distinct radio peaks.
- Polarization
  - Polarization E-vectors indicate the jet magnetic field in the plane of the sky is parallel to the jet throughout the X-ray emitting inner jet, but becomes perpendicular to the jet after the bend, and termination of X-ray emission.

The jet of PKS 0637-752 is the most luminous kpc-scale X-ray jet currently known ($L_{X-ray} \sim 10^{44.6}$ ergs/s). It was also the first discovered with Chandra, and so has been studied extensively. The X-ray jet emission has been interpreted as inverse compton scattering of microwave background photons (IC/CMB). These IC/CMB models of jet X-ray emission imply that the jet bulk velocity remains relativistic ($\Gamma \sim 20$) at hundreds of kpc from the active nucleus (Tavecchio et al., 2000).

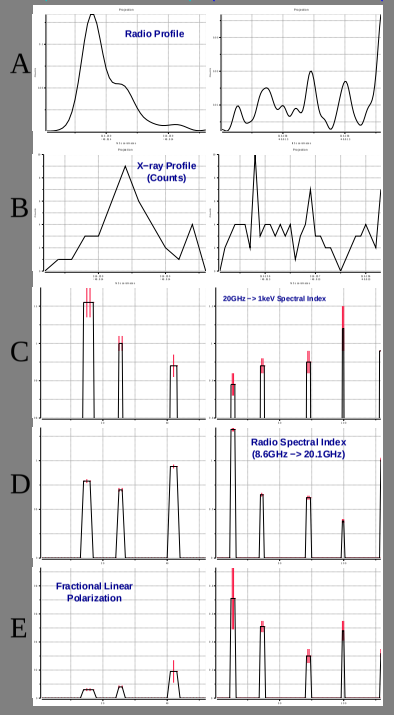


Above Left: 20.16GHz ATCA contour image of PKS 2101-490, showing polarization E-vectors. Length of vectors is proportional to polarized flux density with 2 arcseconds per m Jy. Assuming negligible rotation measure, the direction of the E-vectors is perpendicular to the magnetic field direction in the plane of the sky.

Above Right: Chandra X-ray raw counts (0.5 - 7.0 keV) image of PKS 2101-490 obtained from a 42ks ACIS-S observation. Pixel size is 0.246 arcseconds. Purple corresponds to one count per pixel. The peak counts per pixel in the jet is 3 counts per pixel, displayed as light green, and 2 counts per pixel as light blue. 20.16GHz contours are overlaid.

PKS 2101-490

- Flat spectrum radio quasar at z=1.04
- X-ray Emission
  - Inner X-ray jet is similar to inner jet of PKS 0637-752, being weaker closer to the core, peaking near the bend in the radio jet, then decreasing once again after the bend.
  - Unlike PKS 0637-752, the X-ray emission continues past the bend in the radio jet. The peak in the post-bend X-ray emission clearly precedes the radio peak (termination shock), and is associated with a knot upstream in which the magnetic field in the plane of the sky remains parallel to the jet.
- Radio Emission
  - Overall radio morphology very similar to that of PKS 0637-752.
  - Radio peaks appear to be slightly offset from peaks in X-ray emission.
- Polarization
  - The polarization E-vectors reveal a magnetic field that is aligned with the jet right up until the the termination shock. In both these sources, the X-ray emission is associated with regions in which the magnetic field in the plane of the sky lies parallel to the jet.
  - Fractional linear polarization in the hotspot region is significantly less than that in the inner jet.



Above: Jet profiles along regions shown on X-ray image above. Spectral indices (plots C and D) were calculated as $\alpha_{x1->x2} = -\frac{\log(\frac{x1}{x2})}{\log(\frac{\nu1}{\nu2})}$ Error bars are $\pm 1\sigma$, except for plot C, where error bars are $\pm 1.6\sigma$.